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A revised stratigraphy for the Palaeocene Agatdalen flora (Nuussuaq Peninsula, western Greenland): correlating fossiliferous outcrops, macrofossils, and palynological samples from phosphoritic nodules

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ABSTRACT. The Cretaceous and Palaeogene floras of western Greenland that were initially described as part of the classical work "Flora fossilis arctica" by Oswald Heer in the 19th century are currently under revision. The Nuussuaq Basin has repeatedly been investigated by geologists and marine invertebrate palaeontologists. These studies provide a modern stratigraphic framework and a basis for revisions of various Cretaceous to Eocene floras from this region, and the correlation of fossil material to stratigraphic units and formal formations. This paper is the first in a series of papers that (*i*) correlate macrofossil (museum) material and fossil-rich localities with the modern lithostratigraphic framework, (*ii*) describe new pollen, spores, and other marine/freshwater palynomorphs, and (*iii*) revise the macrofossil remains from the Agatdalen area (particularly the Danian Agatdal Formation). Since the work of B. Eske Koch in the 1960s and 70s, questions emerged about the correlation of plant fossiliferous outcrops and whether the so-called Agatdalen flora, referred to the Agatdal Formation, originates from a single sedimentary unit or not. In this paper, we summarise the stratigraphy of the Agatdalen area and correlate the fossil plant-bearing outcrops described by Koch to the current lithostratigraphy. We establish which plant fossils belong to the Agatdal Formation and re-assign a great number of other plant fossils to their correct formations. New palynological material is briefly described and correlated to the macrofossil localities and the Agatdal Formation. Previous accounts on the macrofossils (leaves, fruits, seeds) are briefly discussed and directions for future revisions are outlined.

KEYWORDS: plant macrofossils, palynomorphs, pollen, spores, phosphoritic nodules, Danian, early Cenozoic

INTRODUCTION

The Nuussuaq Basin in western Greenland (Fig. 1) is one of few places in the Northern Hemisphere with a nearly continuous sedimentary record spanning the mid-Cretaceous (Albian) to the late Palaeogene (middle Eocene). The sedimentary formations were deposited in lacustrine, deltaic, shallow-, and deep-water marine environments, and several formations are rich in plant fossils (Dam et al. 2009). The time period represented by the Nuussuaq Basin palaeofloras covers the prime-time in the evolution and diversification of angiosperms, the origin of many modern lineages (orders, families) until the establishment of the first modern genera (as compiled e.g. in Friis et al. 2011). Moreover, it spans a major extinction event at the Cretaceous-Palaeogene boundary, which is thought to have affected also the flora at a global

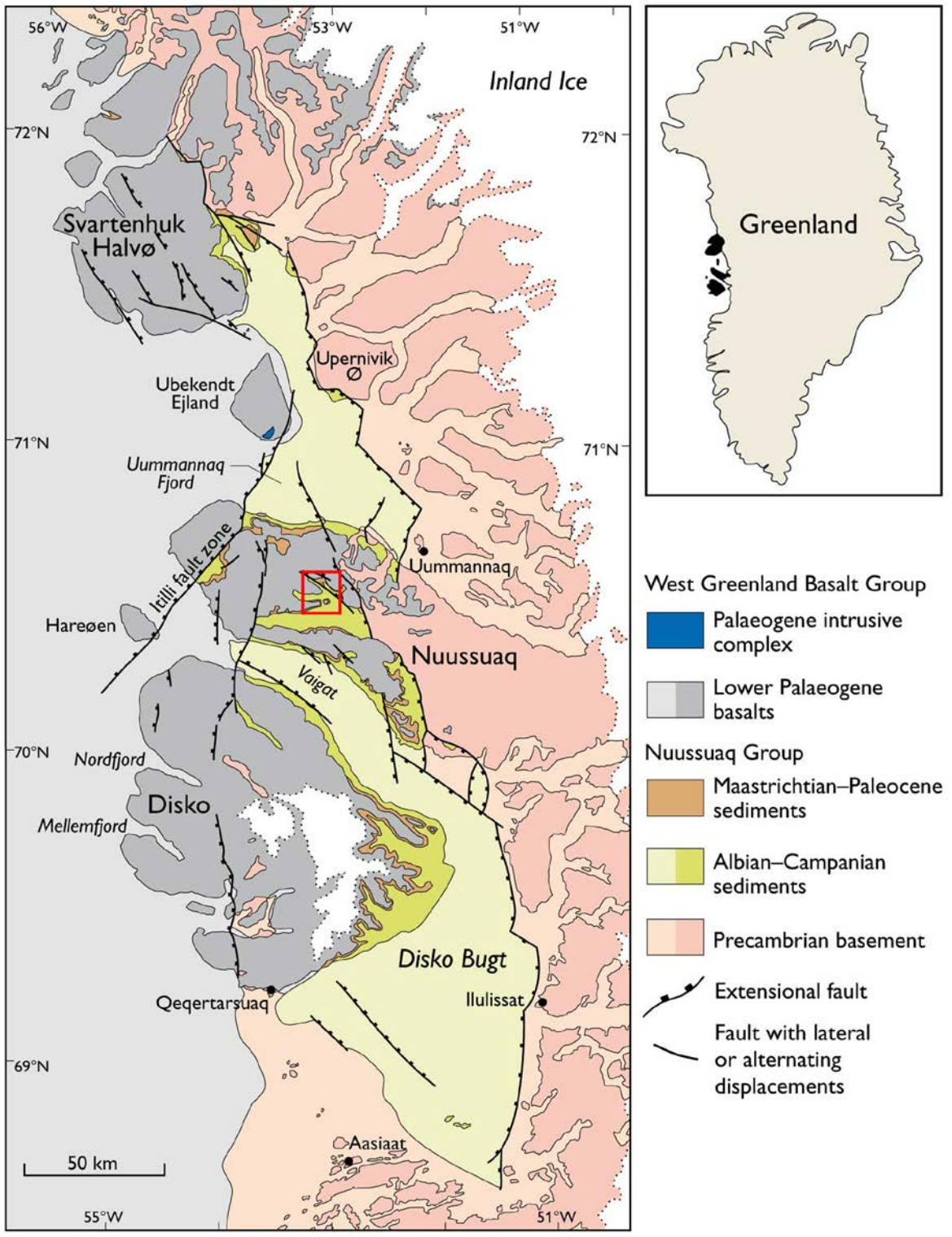

Fig. 1. Geological map of central West Greenland modified after Dam et al. (2009). The location of the Agatdalen area on the Nuussuaq Peninsula is marked with a red box. Light and dark colours refer to the distribution of sedimentary and volcanic rocks on land and in the sea

scale (e.g. Nichols & Johnson 2008). The K-T boundary, which is located in the Kangilia Formation, is exposed at the northern coast of the Nuussuaq Peninsula (Nøhr-Hansen & Dam 1997, Dam et al. 2009, fig. 87). Furthermore, the age and palaeolatitude of the plant fossils make them most valuable for testing an old palaeobiogeographic theory: A. Engler's hypothesis of the Arcto-Tertiary Element, proposing that many dominant elements of today's northern temperate deciduous forests evolved in the High Arctic in the early Cainozoic (Engler 1879).

Dam et al. (2009) revised the lithostratigraphy of the Nuussuaq Basin. Radiometric ages

of the Palaeogene lavas above the sediments provide minimum ages for the plant-bearing sediments (Storey et al. 1998, Schmidt et al. 2005, Larsen et al. 2015). In addition, interspersed pyroclastic layers in the Abraham Member of the Eqalulik Formation can be correlated to the absolute dated lavas by geochemical analyses (Pedersen & Larsen 2006). Based on these studies, we now know the absolute minimum age of the plant-bearing sedimentary rocks representing the Palaeocene and Eocene of the Nuussuaq Basin. Thus, the palaeofloras of the area can now be revised and interpreted in a well-established and precise (down to 2 Ma) temporal (stratigraphic) framework (Grímsson et al. 2014a, Grímsson et al. 2014b, 2015b).

The fossil-rich Upper Cretaceous and Palaeocene sedimentary rocks of the Agatdalen valley in West Greenland were discovered by Alfred Rosenkrantz in 1939, during the second of his "Nûgssuaq Expeditions"; after World War II, the Nûgssuaq Expeditions continued until 1968 and explored the Nuussuaq and Nunavik (Svartenhuk) peninsulas. The Upper Cretaceous and Lower Palaeocene marine deposits contain a rich invertebrate fauna, and extensive collections were brought to Copenhagen for further studies (see p. 15–17 in Dam et al. 2009). For a summary of expeditions, participants, and fossil collections see Rosenkrantz (1970). The plant meso- and macrofossils originally described by Koch (1963, 1972a, b) and collected during the Nûgssuaq Expeditions are stored at the Geological Museum (part of the Danish Natural History Museum) in Copenhagen (section of type collections). The Danish museum hosts additional unpublished plant fossil material from the same expeditions as well as sedimentary rock samples and phosphoritic nodules, kept in the external storehouse of the museum. For this study, we assessed all the original material from Agatdalen still present in the collections of the Geological Museum in Copenhagen described by Koch (1963, 1972a, b). Some of the original material unfortunately is missing. Also, all unpublished plant macrofossils from Agatdalen that are housed in the Danish museum collections and the external storehouse were screened. Most of the plant macrofossils are represented by angiosperm leaves, some by leafy conifer twigs, some by fruits and seeds, and very few by fragments of ferns. Many of the fossils are preserved in sandstones and therefore the higher-order venation of leaves is poorly visible or sometimes not observable.

This paper is the first in a series on the Palaeocene of the Agatdalen area that describes new pollen, spores and other marine/freshwater palynomorphs, and when possible revises the plant macrofossil remains. It aims to correlate the fossil-bearing deposits to the lithostratrigraphy of Dam et al. (2009). A preliminary assessment of the plant fossils stored in the Danish collection is presented as well. Exemplary palynomorphs from phosphoritic nodules of the Agatdal Formation are shown, illustrating their high potential for comprehensive taxonomic studies. A first overview of the palynological diversity is provided.

GEOLOGICAL SETTING OF THE AGATDALEN AREA

The Nuussuaq Basin (Fig. 1) comprises the only exposures of Mesozoic and Palaeogene rocks along the west coast of Greenland (Chalmers & Pulvertaft 2001, Gregersen et al. 2013). The basin comprises sedimentary rocks of Late Cretaceous and Palaeocene age, now referred to the Nuussuaq Group (Dam et al. 2009). These sediments are overlain by a thick succession of Palaeocene to Eocene volcanic rocks, interspersed by sediments, referred to the West Greenland Basalt Group (WGBG; Hald & Pedersen 1975, Pedersen 1985, Larsen & Pedersen 2009, Larsen et al. 2015). The stratigraphy of the Agatdalen area was first outlined by Koch (1959) based on notes from A. Rosenkrantz. Koch collected plant macrofossils mostly in marine deposits in Agatdalen (Koch 1955, 1959, Koch & Pedersen 1960, Koch 1963, 1964, 1972a, b). The Upper Cretaceous marine deposits are referred to the Itilli Formation, the Maastrichtian to Danian marine deposits are referred to the Kangilia Formation, and the overlying Palaeocene marine deposits to the Agatdal and Eqalulik Formations (Fig. 2; see Dam et al. 2009). In the Agatdalen area, the Eqalulik Formation includes the Abraham Member (Fig. 2; Dam et al. 2009). The type locality/section of the Agatdal Formation is the "Store Profil" ("Big Section") in the Turritellakløft gorge, located at 70°35.01′N, 53°08.02′W (Fig. 3). Exposed successions of the Agatdal Formation are

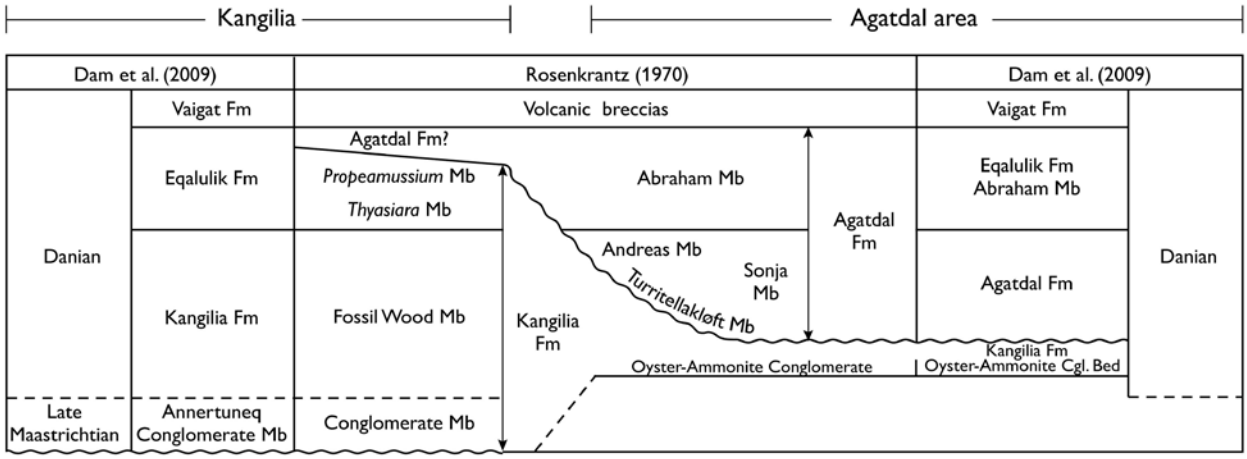

Fig. 2. Lithostratigraphy of the latest Cretaceous and Danian siliciclastic sediments exposed in Agatdalen and at the north coast of Nuussuaq, central West Greenland. The lithostratigraphy was originally established by Rosenkrantz (1970) and revised by Dam et al. (2009). The prominent Annertuneq Conglomerate Member at the base of the Kangilia Formation, at Kangilia and other localities in northern Nuussuaq, was considered as the basal Danian unit and was correlated to the Oyster-Ammonite Conglomerate Bed in Agatdalen by Rosenkrantz (1970). It is now known that the Maastrichtian–Danian boundary is located in the lower part of the Kangilia Formation (Nøhr-Hansen & Dam 1997) and that the Oyster-Ammonite Conglomerate Bed is younger than the Conglomerate Member (Dam et al. 2009). The Agatdal Formation is restricted to the Agatdalen area and is interpreted as a submarine turbidity channel complex (Dam et al. 2009)

18–65 m thick and reach their maximum thickness in the type section "Store Profil" in the Turritellakløft gorge. In the GRO#3 well (western Nuussuaq) the Agatdal Formation is up to 250 m thick (Dam et al. 2009).

The sediments in the Agatdalen area are overlain by volcanic rocks, hyaloclastite breccias, and subaerial lava flows of the late Danian Vaigat Formation (Figs 2–3), which is the oldest formation belonging to the West Greenland Basalt Group (Hald & Pedersen 1975, Pedersen 1985, Larsen & Pedersen 2009). The lowest part of the Vaigat Formation has not been radiometrically dated, but it is normally magnetised and can be referred to magnetic polarity chron C27n (Fig. 5; Riisager & Abrahamsen 1999). The age of the volcanic Naujánguit Member, of the Vaigat Fm, is 61.2±0.5 Ma (Larsen et al. 2015). The geological map in Figure 3 shows the distribution of the sedimentary formations but not the subdivision of the volcanic rocks. The latter are illustrated in a geological section from central Nuussuaq by Pedersen et al. (2002). This section includes Tunoqqu, a mountain at the southern end of Agatdalen. In the following, we give a short description of the formations linked to fossiliferous beds in the Agatdalen area.

The **Atane Formation** comprises fluvial, deltaic and marine deposits of Albian to Santonian age (Dam et al. 2009). The upper part of the Atane Formation, the Qilakitsoq Member, is known from outcrops at Tunoqqu and Kangersooq up to 700 m a.s.l and from boreholes in the Agatdalen valley (Dam et al. 2000). In the Agatdalen area the Atane Formation is dominated by marine delta front and shoreface deposits of late Santonian age (Dam et al. 2000). The Qilakitsoq Member is unconformably overlain by deep-water marine sediments of the Aaffarsuaq Member of the Itilli Formation (Dam et al. 2000, 2009).

The **Itilli Formation,** exposed at Itinnera, at Tunoqqu, and at Scaphitesnæsen (Fig. 3), comprises deep marine mudstones and turbiditic sandstones of late Turonian to early Maastrichtian age (Dam et al. 2009). Rosenkrantz (1970) and Henderson et al. (1976) referred to these sediments as "Marine Upper Cretaceous". In the Agatdalen area the Itilli Formation is represented by the Aaffarsuaq Member, which comprises marine mudstones interbedded with marine intraformational conglomerates interpreted as turbidite channel deposits. The erosional, lower boundary of the Itilli Formation is exposed at Tunoqqu and on the northern slopes of the Aaffarsuaq valley west of Tunoqqu (Dam et al. 2009, fig. 82). The boundary is also recorded in borehole GGU 400702 in the Agatdalen valley. The upper boundary of the Itilli Formation is well known from Kangilia and other localities on the north coast of the Nuussuaq Peninsula (Fig. 1). In the Agatdalen area, the boundary is rarely exposed except possibly at locality 7 (Kangersooq, Nuilaasassuaq; Fig. 4). The Itilli Formation has a fauna of ammonites (Birkelund 1965, Kennedy et al. 1999). The remaining invertebrate fauna was

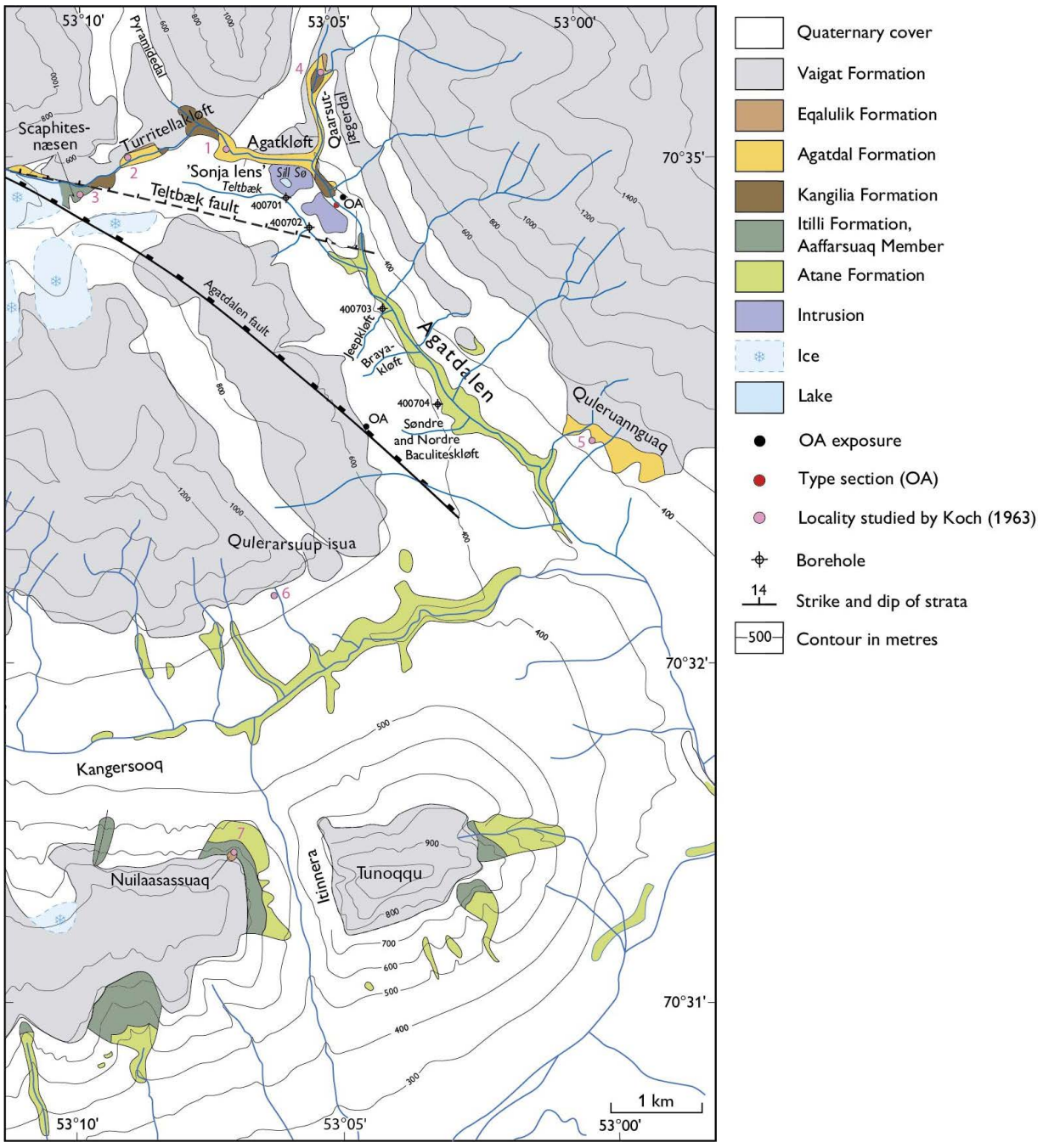

Fig. 3. Geological map of the Agatdalen area, central Nuussuaq Peninsula, West Greenland based on Rosenkrantz et al. (1974) and Dam et al. (2000, 2009). Outcrops are mostly found in river sections. The relatively small outcrops and the significant lateral variation in sedimentary facies (Fig. 5) complicates the correlation between the outcrops. Seven localities, 1–7, studied by Koch (1963) are indicated. The volcanic lithostratigraphy for part of the outcrops was mapped by Pedersen et al. (2002)

listed by Rosenkrantz (1970) and Dam et al. (2009, and references therein).

The **Kangilia Formation** was established by Rosenkrantz (1970) and was revised by Dam et al. (2009). The formation is of late Maastrichtian and Danian age, belonging to the calcareous nannoplankton biozones NP3–NP4 (Fig. 5; Dam et al. 2009). The Kangilia Formation comprises deep water marine mudstones with intraformational conglomerate(s) deposited in submarine turbidite channels. On the north coast of Nuussuaq and in the Tunorsuaq valley the base of the Kangilia Formation consists of conglomerates and sandstones of the Annertuneq Conglomerate Member succeeded by dark grey mudstones (see fig. 74 in Dam et al. 2009). In the Agatdalen area the Kangilia Formation is known from small outcrops, which include the erosive boundary to the overlying Agatdal Formation (Figs 2 and 4). The Oyster-Ammonite Conglomerate Bed in Agatdalen comprises reworked Danian fossils

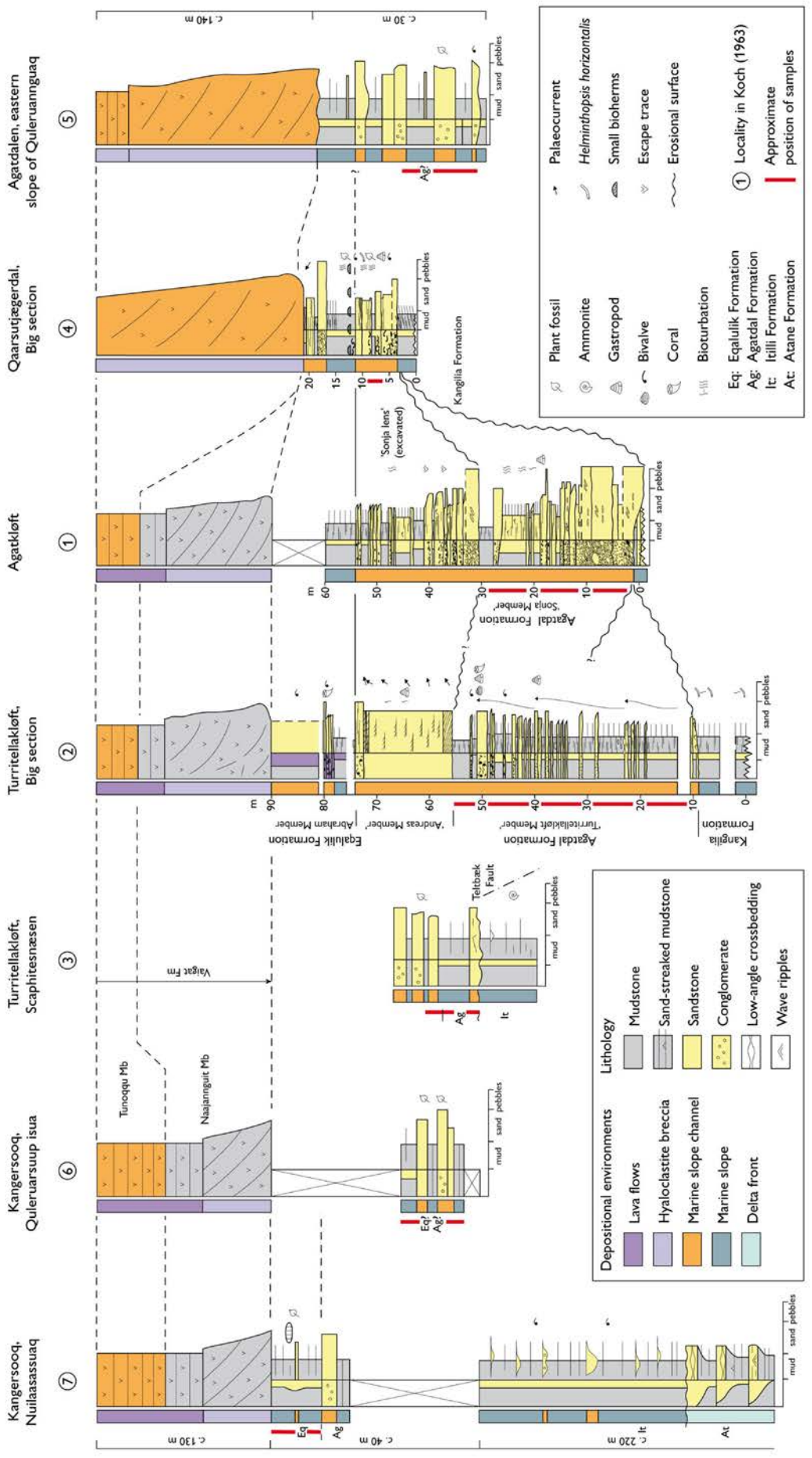

Fig. 4. The stratigraphical successions at the seven localities studied by Koch (1963). The detailed logs from localities 1, 2, and 4 are from Dam et al. (2009). The simplified logs from localities 3 and 5–7 are based on the descriptions in Koch (1963) and Dam et al. (2000, 2009). The volcanic lithostratigraphy is from Pedersen et al. (2002) and emended based on unpublished data (A.K. Pedersen, pers. comm., 2014)

(Dam et al. 2009). It is therefore younger than the Maastrichtian Annertuneq Conglomerate Member (Nøhr-Hansen & Dam 1997, Dam et al. 2009) and has been included in the Kangilia Formation.

The **Agatdal Formation** was established by Rosenkrantz (1970) based on outcrops restricted to Agatdalen and subdivided into four informal members (Fig. 2). In the revision by Dam et al. (2009), three members were emended and the syn-volcanic Abraham Member was moved to the new Eqalulik Formation. The Agatdal Formation is younger than the Kangilia Formation in the Agatdalen area, but contemporaneous with the Kangilia Formation in the northern part of the Nuussuaq Peninsula (Kangilia, Fig. 2). The formation comprises deep-water marine mudstones, turbidite sandstones, and conglomerates and shows large lateral and vertical facies variability (Fig. 4). The sediments do not contain volcaniclastic material. The formation is interpreted as the fill of a submarine valley incised into the Kangilia Formation. The Agatdal Formation has a rich marine invertebrate fauna and was studied extensively by members of the Nuussuaq Expeditions and in newer studies (e.g. Bendix-Almgreen 1969, Hansen 1970, Rosenkrantz 1970, Szczechura 1971, Floris 1972, Perch-Nielsen 1973, Hansen 1976, Kollmann & Peel 1983, Collins & Wienberg Rasmussen 1992, Petersen & Vedelsby 2000). The Agatdal Formation is of early Palaeocene (late Danian) age (64–62 Ma; calcareous nannoplankton biozones NP3–NP4; Dam et al. 2009).

The **Eqalulik Formation** was established by Dam et al. (2009) for the syn-volcanic marine sediments overlying a regional flooding surface in the Nuussuaq Basin (Figs 2 and 4). The age of the formation is latest Danian–early Selandian, calcareous nannoplankton biozones NP4–base NP5 (Fig. 5; Dam et al. 2009). The oldest parts of the formation can be found in the western part of the Nuussuaq Peninsula, where it is coeval to the Anaanaa Member of the Vaigat Formation (Fig. 5). In the Agatdalen area the lower part consists of tuffaceous mudstones and constitutes the Abraham Member, which is ca 10–20 m thick. The Abraham Member contains spherules of volcanic glass or tuff with a distinct chemical composition known only from the volcanic Asuk Member erupted from the Ilugissoq graphite andesite volcano (Pedersen & Larsen 2006). The Abraham Member thereby provides a link between the volcanic and the sedimentary successions, and a correlation to the palaeomagnetic zonation (Fig. 5). In the eastern part of the Agatdalen area, the Eqalulik Formation is overlain by volcanic breccias of the Tunoqqu Member, the youngest unit within the volcanic Naujánguit Member of the Vaigat Fm, and thus demonstrates that the Eqalulik Formation is a time-transgressive unit. In northern Nuussuaq (Kangilia) the Eqalulik Formation overlies the Kangilia Formation (Fig. 2). Geological evidence suggests that the volcanic Vaigat Formation prograded from west to east as hyaloclastic breccias overlain by subaerial lava flows (Pedersen et al. 2006). This pattern is also recognised in the Agatdalen area, where the Tunoqqu Member of the volcanic Vaigat Formation is seen in lava facies to the west (localities 1–3, 6, 7) and in both breccia and lava facies to the east (localities 4 and 5; Fig. 4).

THE PLANT MACROFOSSIL SITES OF THE AGADALEN AREA

The original work on the Agatdalen flora by Koch (1963) includes seven localities. Three localities, numbers 1 (Agatkløft), 4 (Qaarsutjægerdal, Big section), and 6 (Kangersooq, Qulerarsuup isua), account for most of the plant macrofossils described in this paper by Koch. No fossils were described or figured from localities 2 (Turritellakløft, Big section) and 3 (Turritellakløft, Scaphitesnæsen), but it is mentioned that a few plant fossils were found at locality 2, and at locality 3 there are plenty of fossil fruits. From localities 5 (Agatdalen, eastern slope of Quleruannguaq) and 7 (Kangersooq, Nuilaasassuaq) only a single taxon each was described (Tab. 1). The fruits/seeds later described by Koch (1972a, b) originate mostly from locality 3 (Turritellakløft, Scaphitesnæsen); the rest were from localities 1 (Agatkløft) and 4 (Qaarsutjægerdal, Big section). Koch (1963, 1972a, b) described the sites with plant macrofossils in the Agatdalen area only briefly. Neither he nor his contemporaries indicated the fossiliferous deposits on stratigraphical logs of the successions. Figure 4 shows simplified stratigraphic logs for these seven localities, which are briefly described in the following.

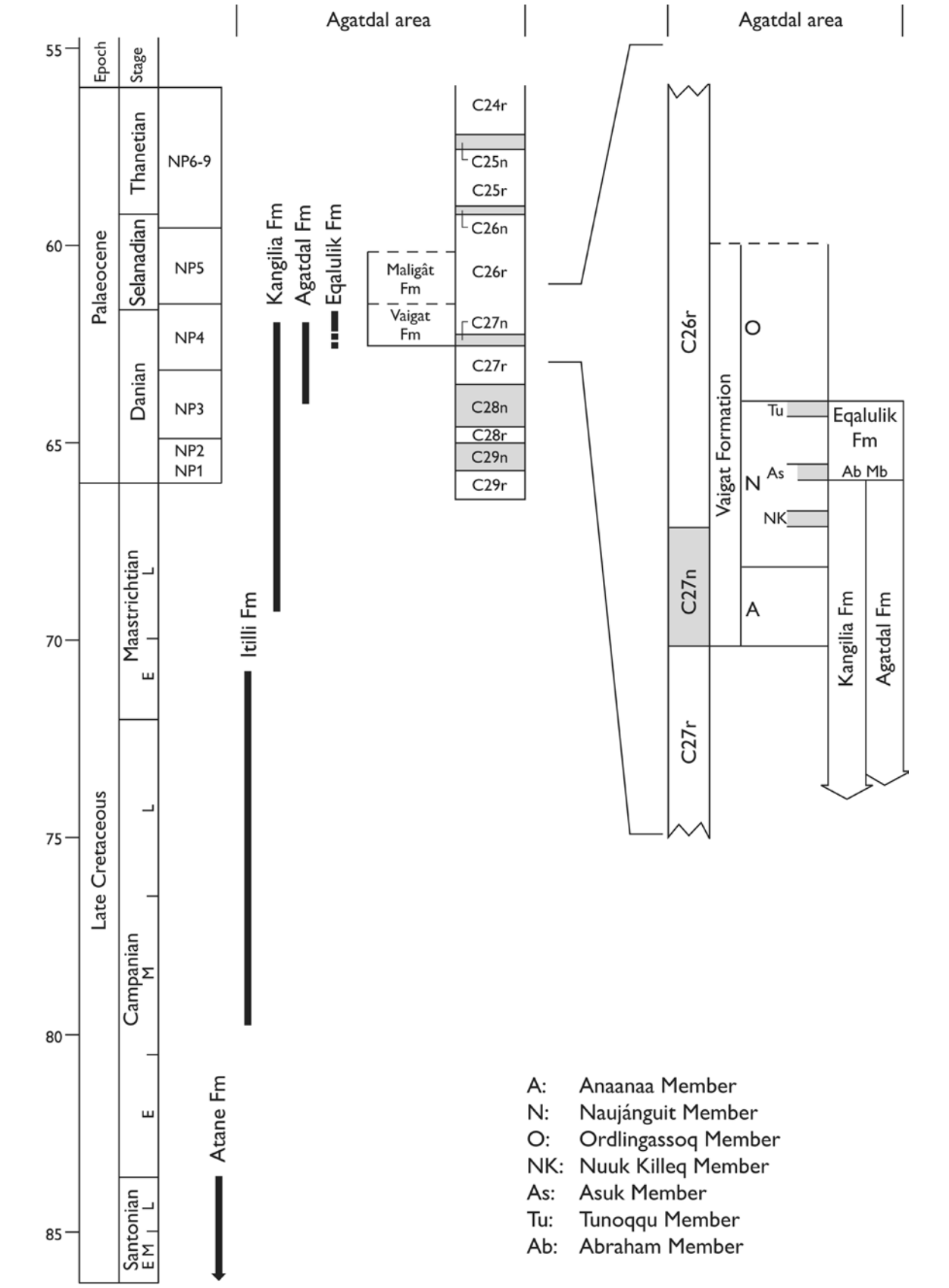

Fig. 5. Stratigraphy of the Agatdalen area, central Nuussuaq Peninsula, where the Late Cretaceous and Palaeocene siliciclastic sediments are referred to the Atane-, Itilli-, Kangilia-, Agatdal-, and Eqalulik formations, overlain by volcanic rocks of the late Danian to Selandian Vaigat Formation. The late Danian of the Agatdalen area is shown in greater detail in the right part of the figure. The Abraham Member constitutes the basal part of the synvolcanic Eqalulik Formation. The Abraham Member contains tuff, which represents the volcanic Asuk Member. The sedimentary and volcanic lithostratigraphies are thus correlated in the Agatdalen area. The ages in the left part of the figure are from Gradstein et al. (2012)

Locality 1. Agatkløft – This locality is one of three, where the profile starts with the Kangilia Fm, discordantly overlain by the Agatdal Fm. The Agatdal Fm comprises a sandstone-dominated unit overlain by bituminous shale. The Agatdal Formation is overlain by landslipped volcanic rocks and hyaloclastite breccias, which again are overlain by lava flows of the Tunoqqu Member (Fig. 4).

Locality 2. Turritellakløft, Big section – A small outcrop of the Kangilia Formation is indicated by Rosenkrantz (1970). As at locality 1, it is discordantly overlain by the mudstones and sandstones of the Agatdal Formation, the latter containing the plant fossils. The Agatdal Formation is overlain by tuffaceous mudstones of the Abraham Member (Eqalulik Formation), see Dam et al. (2009). The Eqalulik Formation is overlain by hyaloclastite breccias of the Naujánguit Member (Vaigat Fm; A.K. Pedersen, pers. comm., 2014; Fig. 4).

Locality 3. Turritellakløft, Scaphitesnæsen – Late Cretaceous mudstones (the Itilli Formation, only exposed here and at locality 7) are overlain by a thin section of the Turritellakløft Member (of Rosenkrantz 1970), i.e. the Agatdalen Fm. These Palaeocene deposits contain plenty of plant fossils together with marine invertebrates (Koch 1963). The sediments are overlain by landslipped volcanic rocks, and volcanic breccias of the Naujánguit Member (A.K. Pedersen, pers. comm. 2014; Fig. 4).

Locality 4. Qaarsutjægerdal, Big section (Qaersutjægerdal) – Mudstones of the Kangilia Formation are discordantly overlain by fossiliferous sandstones of the Turritellakløft Member (Rosenkrantz 1970), succeeded by mudstones, conglomerates, and sandstone of the Abraham Member (Rosenkrantz 1970). The overlying volcanic breccia is referred to the Tunoqqu Member of the Vaigat Formation (A.K. Pedersen, pers. comm. 2014; Fig. 4). The plant fossils derive from a loose ochreous sandstone (Koch 1963), which is part of the Turritellakløft Member of Rosenkrantz (1970). Dam et al. (2009) indicate plant remains in both the Agatdal Formation and the Eqalulik Formation (Fig. 4).

Locality 5. Agatdalen, east slope of Qulleruannguaq (Quleruánguaq) – Mudstones and sandstones, containing plant fossils and marine molluscs, are exposed 20–30 m below the base of the volcanic breccias (Koch 1963). The presence of tuff beds is not mentioned in the description of the outcrop. This may suggest that the sediments belong to the Agatdal Fm, as shown by (Dam et al. 2009, fig. 113), but this assumption needs further confirmation. The volcanic breccias represent the Tunoqqu Member, and are overlain by a thin succession of subaerial lava flows of the Tunoqqu Member (A.K. Pedersen, pers. comm., 2014; Fig. 4).

Locality 6. Kangersooq, Qulerarsuup isua (Kangersôq Qulerarssûp isua) – Deltaic sandstones and mudstones of the Upper Cretaceous Atane Formation are overlain by Palaeocene sandstones and mudstones with plant fossils 45 m below the basalt breccia (Koch 1963). Unpublished data indicate the presence of a thin unit of the Eqalulik Formation below the breccias (A.K. Pedersen, pers. comm., 2014; not shown in Fig. 4). If the thickness of the Abraham Member is uniformly less than 20 m, the vertical distance between the plant-bearing beds and the breccias suggests that the fossils represent the Agatdal Formation rather than the Eqalulik Formation. The sediments are overlain by volcanic breccias of the Naujánguit Member and by lava flows of the Tunoqqu Member (A.K. Pedersen, pers. comm., 2014; Fig. 4).

Locality 7. Kangersooq, Nuilaasarsuaq (Kangersôq at Nuilaussarssuaq) – The deltaic Atane Formation, outcropping only at this locality, is overlain by turbiditic sandstones and mudstones of the Itilli Formation; the latter is also found at locality 3 (Turritellakløft, Scaphitesnæsen). The Cretaceous sediments are overlain by volcanic breccias and lavas (Pedersen et al. 2002, Dam et al. 2009). Small outcrops of the Kangilia Fm and Agatdal Fm are reported by Rosenkrantz (1970) and Rosenkrantz et al. (1974). Koch (1963) found plant fossils in Palaeocene sediments immediately below the volcanic breccias. It is therefore probable that the fossils derive from a small outcrop of the Eqalulik Formation. The overlying breccias, as well as the oldest subaerial lavas, represent the Naujánguit Member. Slightly younger lava flows belong to the Tunoqqu Member (Pedersen et al. 2002; Fig. 4).

None of the Agatdalen fossils described by Koch (1963, 1972a, b) or any other material screened by us stored in Copenhagen originate from the three oldest formations found in the

Table 1. Comparison of plant fossil localities in the Agatdalen area, Nuussuaq Peninsula, central West Greenland

Locality (see Fig. 3)		Number of taxa identified and figured by Koch (1963, 1972a,b)	Specimens in collection	Formation	Further illustrations
1	Agatkløft	23 macrofossil (including 3 "design"), 1 mesofossil	59	Agatdal	See fig. 3 in Koch (1963), fig. 314 in Henderson et al. (1976), and fig. 117 and pl. 3 in Dam et al. (2009).
2	Turritellakløft, Big section	No taxa described from this locality.	–	Agatdal	See figs 4a and 5 in Rosenkrantz (1970), and fig. 114 and pl. 3 in Dam et al. (2009).
3	Turritellakløft, Scaphitesnæsen	2 mesofossil	26	Agatdal	See fig. 5 in Birkelund (1965).
4	Qaarsutjægerdal, Big section (Qaersutjægerdal)	10 macrofossil (including 3 "design"), 2 mesofossil	18	Agatdal	See fig. 4b in Rosenkrantz (1970), fig. 5 in Hansen (1970), and fig. 115 and pl. 3 in Dam et al. (2009).
5	Agatdalen, east slope of Quleruaanguaq (Quleruánguaq)	1 macrofossil (cf. *Rhododendron* sp.)	1	?Agatdal	See fig. 113 in Dam et al. (2009). The outcrop is shown on the geological map of Rosenkrantz et al. (1974).
6	Kangersooq Qulerarsuup isua (Kangersôq Qulerarssûp isua)	18 macrofossil (including 4 "design")	87	Agatdal or Eqalulik	The outcrop is not shown on the geological map of Rosenkrantz et al. (1974).
7	Kangersooq at Nuilaasarsuaq (Kangersôq at Nuilaussarssuaq)	*Cercidiphyllum arcticum* (mentioned in the text)	0	Eqalulik	See geological map of Rosenkrantz et al. (1974), and fig. 82 in Dam et al. (2009).

outcrops (Atane Fm, Itilli Fm, Kangilia Fm). Most are from the Agatdal Fm, with a few certain and several possible exceptions that can be associated with the younger Eqalulik Fm. Following the publications of Koch (1963, 1972a, b), these fossils have been treated as belonging to a single contemporaneous flora, often referred to as the Agatdal/-en flora or flora of the Agatdal Formation (Koch 1964, Pedersen 1976, Dam et al. 2009). The plant fossils from Agatdalen have also been grouped with other Palaeocene to Eocene plant remains from various western Greenland sites under the so-called early Palaeocene Atanikerluk (or Atanikerdluk) floral province (e.g. Mai 1995, Kvaček 2010). Based on the revised stratigraphy presented in Figure 4 it is clear that the plant macro- and mesofossil specimens figured and described by Koch (1963, 1972a, b) originate from either the Agatdal Formation or the younger Equalulik Formation (Tabs 1 and 2). It is uncertain if the fossils from localities 5 (Agatdalen, eastern slope of Quleruannguaq) and 6 (Kangersooq, Quleruarsuup isua) described by Koch (1963) originate from the Agatdal Formation or the Eqalulik Formation. Of the 186 specimens described/figured in Koch (1963, 1972a, b), 21 are not from the Agatdalen area, but from Cretaceous to Eocene sites on the Qeqertarsuatsiaq (Hareøen) and Qeqertarsuaq (Disko) islands, and coastal sites along the southern part of the Nuussuaq Peninsula. The other ca 130 specimens originate either from the Agatdal Formation or the Eqalulik Formation (Tab. 2). Of these, 68 specimens can be ascribed to the Agatdal Formation with certainty, and for 61 of the specimens it is completely unclear if they belong to the Agatdal or the Eqalulik Formation. The plant macrofossil described by Koch (1963) from locality 7 (Kangersooq, Nuilaasassuaq) originates from the Eqalulik Formation.

PHOSPHORITIC NODULES AND A FIRST ASSESSMENT OF THE PALYNOMORPH DIVERSITY OF THE AGATDAL FORMATION

The phosphoritic nodules (Fig. 6) comprising the palynomorphs investigated during this study all originate from the Agatdal Formation and were collected at locality 1 (Agatkløft) from sediments previously assigned to the Sonja Member and locality 2 (Turritellakløft, Big section) from sediments previously assigned to the Turritellakløft Member (Koch 1959, 1963, Rosenkrantz 1970). The nodules are up to 10 cm in diameter. They generally have a light-grey to brownish colour in cross section. The surface of the nodules is often smooth and shiny with dark grey colours (Fig. 6). The nodules have a distinct nucleus of variable size and origin (cone, seed, fruit,

Table 2. Plant fossils described by Koch (1963, 1972a, b) and their affiliation to localities and formations, with notes on their taxonomic status

Mus. nr.	Field nr.	Taxonomic affiliation according Koch*	Published in	Figured in	Status in collection	Locality	Formation	Notes on taxonomy
10350	35492-4	*Cladophlebis groenlandica* (Heer) Bell	Koch 1963	pl. 1, fig. 1	Present	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	Affiliation unclear
10351	35492-2	*Cladophlebis groenlandica* (Heer) Bell	Koch 1963	pl. 1, fig. 2	Present	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	Affiliation unclear
10352	18061-2	*Hemitelites torelli* Heer	Koch 1963	pl. 1, figs 4, 6	Present	Qaarsutjægerdal, Big section	Agatdal	Affiliation unclear
10353	12896-219	*Ginkgo adiantoides* (Unger) Shap.	Koch 1963	pl. 1, fig. 3	Present	Agatkløft	Agatdal	Correct genus, new species
10354	35492	*Ginkgo adiantoides* (Unger) Shap.	Koch 1963	pl. 1, fig. 5	Present	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	Correct genus, new species
10355	35492-3	*Metasequoia occidentalis* (Newb.) Chaney	Koch 1963	pl. 2, fig. 1	Present	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	Valid
10356	28084-3	*Metasequoia occidentalis* (Newb.) Chaney	Koch 1963	pl. 2, fig. 2	Present	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	Valid
10357	35492-153	*Metasequoia occidentalis* (Newb.) Chaney	Koch 1963	pl. 2, figs 3, 4	Part present, counterpart missing	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	Valid
10358	1865.801a	*Metasequoia occidentalis* (Newb.) Chaney	Koch 1963	text-fig. 7; pl. 2, fig. 5	Not checked	Not from Agatdalen area (Atanikerluk, south coast of Nuussuaq)	Quikavsak ?	Not checked
10359	35492-152	*Metasequoia occidentalis* (Newb.) Chaney	Koch 1963	pl. 3, fig. 1	Present	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	Valid
10360A	12896-121	*Metasequoia occidentalis* (Newb.) Chaney	Koch 1963	pl. 3, fig. 2	Present	Agatkløft	Agatdal	Valid
10360B	12896-169	*Metasequoia occidentalis* (Newb.) Chaney	Koch 1963	pl. 3, fig. 3	Present	Agatkløft	Agatdal	Valid
10361	35492-152	*Metasequoia occidentalis* (Newb.) Chaney	Koch 1963	pl. 3, fig. 4	Present	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	Valid
10362	35492-6	*Metasequoia occidentalis* (Newb.) Chaney	Koch 1963	pl. 3, fig. 5	Present	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	Valid
10363	28084-2	*Metasequoia occidentalis* (Newb.) Chaney	Koch 1963	pl. 3, fig. 6	Present	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	Valid
10364	35492-154	*Metasequoia occidentalis* (Newb.) Chaney	Koch 1963	pl. 3, fig. 7	Present	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	Valid
10365	35492-150	*Metasequoia occidentalis* (Newb.) Chaney	Koch 1963	pl. 4, fig. 1	Missing	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	Valid
10366	35492-149	*Metasequoia occidentalis* (Newb.) Chaney	Koch 1963	pl. 4, fig. 2	Missing	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	Valid
10367	35492-148	*Metasequoia occidentalis* (Newb.) Chaney	Koch 1963	pl. 4, fig. 3	Present	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	Valid
10368	8082-3	*Metasequoia occidentalis* (Newb.) Chaney	Koch 1963	pl. 4, figs 4-6	Present	Qaarsutjægerdal, Big section	Agatdal	Valid
10369	35492-24	*Quercophyllum groenlandicus* (Heer) Koch	Koch 1963	pl. 5, fig. 1	Present	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	Revised: *Fagopsiphyllum*
10370	35492-21	*Quercophyllum groenlandicus* (Heer) Koch	Koch 1963	pl. 5, fig. 2	Present	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	Revised: *Fagopsiphyllum*
10371	35492-20	*Quercophyllum groenlandicus* (Heer) Koch	Koch 1963	pl. 5, fig. 3	Present	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	Revised: *Fagopsiphyllum*
10372	35492-22	*Quercophyllum groenlandicus* (Heer) Koch	Koch 1963	pl. 5, fig. 4	Present	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	Revised: *Fagopsiphyllum*
10373	35492-27	*Quercophyllum groenlandicus* (Heer) Koch	Koch 1963	pl. 6: fig. 1	Present	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	Revised: *Fagopsiphyllum*
10374	35492-26	*Quercophyllum groenlandicus* (Heer) Koch	Koch 1963	pl. 6, fig. 2	Present	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	Revised: *Fagopsiphyllum*
10375	35493-20	*Quercophyllum groenlandicus* (Heer) Koch	Koch 1963	pl. 6, fig. 3	Present	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	Revised: *Fagopsiphyllum*
10376	35249-1	*Quercophyllum furcinervis americana* (Rossm.) Knowlt.	Koch 1963	pl. 6, fig. 4	Present	Qaarsutjægerdal, Big section	Agatdal	→ *Eotrigonobalanus* (?)
10377	12896-123	*Quercophyllum furcinervis americana* (Rossm.) Knowlt.	Koch 1963	pl. 6, fig. 5	Present	Agatkløft	Agatdal	→ *Eotrigonobalanus* (?)
10378	12896-129	*Quercophyllum furcinervis americana* (Rossm.) Knowlt.	Koch 1963	pl. 6, fig. 6	Part missing, counterpart present	Agatkløft	Agatdal	→ *Eotrigonobalanus* (?)
10379	12896-95	*Quercophyllum furcinervis americana* (Rossm.) Knowlt.	Koch 1963	pl. 7, fig. 1	Present	Agatkløft	Agatdal	→ *Eotrigonobalanus* (?)
10380	8083	*Quercophyllum furcinervis americana* (Rossm.) Knowlt.	Koch 1963	pl. 7, fig. 2	Present	Agatkløft	Agatdal	→ *Eotrigonobalanus* (?)
6357		*Castanea atavia* Unger	Koch 1963	pl. 7, fig. 3	Not checked	Not from Agatdalen area (Atanikerluk, south coast of Nuussuaq)	Atanikerluk	Not checked
10381	12896-84	cf. *Populus* sp.	Koch 1963	pl. 8, fig. 1	Present	Agatkløft	Agatdal	Affiliation unclear
10382	28955-27	*Dryophyllum* cf. *subfalcatum* Lesq.	Koch 1963	pl. 8, figs 2, 3	Present	Qaarsutjægerdal, Big section	Agatdal	→ Castanoideae (?)
10383	12896-18	*Cupuliferites angmartusuticus* Koch	Koch 1963	pl. 8, fig. 4	Present, out of place	Agatkløft	Agatdal	→ *Eotrigonobalanus* (?)
10384	12896-70	*Cupuliferites angmartusuticus* Koch	Koch 1963	pl. 9, fig. 1	Present	Agatkløft	Agatdal	→ *Eotrigonobalanus* (?)
10385	12896-96	*Cupuliferites angmartusuticus* Koch	Koch 1963	pl. 10, fig. 1	Present	Agatkløft	Agatdal	→ *Eotrigonobalanus* (?)
10386	35484	*Cupuliferites angmartusuticus* Koch	Koch 1963	pl. 10, fig. 2	Present	Agatkløft	Agatdal	→ *Eotrigonobalanus* (?)
10387	35492-38	*Juglandiphyllum denticulatum* (Heer) Koch	Koch 1963	pl. 10, fig. 3	Present	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	Revised: *Platanus bella*
10388	12896-82	*Juglandiphyllum denticulatum* (Heer) Koch	Koch 1963	pl. 11, fig. 1	Present	Agatkløft	Agatdal	Revised: *Platanus bella*
10389	35492-41	*Juglandiphyllum denticulatum* (Heer) Koch	Koch 1963	pl. 11, fig. 2	Part missing, counterpart present	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	Revised: *Platanus bella*
10390	12896-89	*Juglandiphyllum denticulatum* (Heer) Koch	Koch 1963	pl. 13, fig. 1	Present	Agatkløft	Agatdal	Revised: *Platanus bella*
10391		*Juglandiphyllum denticulatum* (Heer) Koch	Koch 1963	pl. 14, fig. 1	Present	Not from Agatdalen area (Atanikerluk, south coast of Nuussuaq)	Quikavsak ?	Revised: *Platanus bella*
10392	s.n.	*Juglandiphyllum denticulatum* (Heer) Koch	Koch 1963	pl. 14, fig. 2	Missing	Not from Agatdalen area (Atanikerluk, south coast of Nuussuaq)	Quikavsak ?	Revised: *Platanus bella*
10393	12896-33	cf. *Liriodendron* sp.	Koch 1963	pl. 16, fig. 1	Present	Agatkløft	Agatdal	Affiliation unclear
10394	35492-87	*Cercidiphyllum arcticum* (Heer) Brown	Koch 1963	pl. 16, fig. 2	Present	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	→ *Trochodendroides* (?)
10395	12896-71	*Cercidiphyllum arcticum* (Heer) Brown	Koch 1963	pl. 16, fig. 3	Present	Agatkløft	Agatdal	→ *Trochodendroides* (?)
10396	35492-76	*Cercidiphyllum arcticum* (Heer) Brown	Koch 1963	pl. 17, figs 1, 2	Part present, counterpart missing	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	→ *Trochodendroides* (?)
10397	35492-115	*Cercidiphyllum arcticum* (Heer) Brown	Koch 1963	pl. 17, fig. 3	Present	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	→ *Trochodendroides* (?)
10398	35492-54	*Cercidiphyllum arcticum* (Heer) Brown	Koch 1963	pl. 18, fig. 1	Present	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	→ *Trochodendroides* (?)

Table 2. Plant fossils described by Koch (1963, 1972a, b) – continued

Mus. nr.	Field nr.	Taxonomic affiliation according Koch*	Published in	Figured in	Status in collection	Locality	Formation	Notes on taxonomy
10399	35492-95	*Cercidiphyllum arcticum* (Heer) Brown	Koch 1963	pl. 18, fig. 2	Present	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	→ *Trochodendroides* (?)
10400	35492-25	*Cercidiphyllum arcticum* (Heer) Brown	Koch 1963	pl. 18, fig. 3	Present	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	→ *Trochodendroides* (?)
10401	35492-70	*Cercidiphyllum arcticum* (Heer) Brown	Koch 1963	pl. 19, fig. 1	Present	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	→ *Trochodendroides* (?)
10402	12896-152	*Cercidiphyllum arcticum* (Heer) Brown	Koch 1963	pl. 19, fig. 2	Present	Agatkløft	Agatdal	→ *Trochodendroides* (?)
10403	12896-150	*Cercidiphyllum arcticum* (Heer) Brown	Koch 1963	pl. 19, fig. 3	Present	Agatkløft	Agatdal	→ *Trochodendroides* (?)
10404	35492-121	*Cercidiphyllum arcticum* (Heer) Brown	Koch 1963	pl. 20, fig. 1	Present	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	→ *Trochodendroides* (?)
10405	35492-70	*Corylopsiphyllum groenlandicum* Koch	Koch 1963	pl. 20, fig. 2	Present	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	Hamamelidaceae (?*Corylopsis*)
10406	35492-72	*Corylopsiphyllum groenlandicum* Koch	Koch 1963	pl. 21, figs 1, 2	Present	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	Hamamelidaceae (?*Corylopsis*)
10407	35492-72	*Corylopsiphyllum groenlandicum* Koch	Koch 1963	pl. 22, fig. 1	Present	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	Hamamelidaceae (?*Corylopsis*)
10408	28084-6	*Corylopsiphyllum groenlandicum* Koch	Koch 1963	pl. 22, fig. 2	Present	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	Hamamelidaceae (?*Corylopsis*)
?	35492-155	*Platanus* sp. cf. *aceroides* Göpp.	Koch 1963	pl. 24, fig. 1	Missing	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	Correct genus, species unclear
6660	12896-6	*Viburnum whymperi* Heer	Koch 1963	pl. 24, fig. 2	Not checked	Not from Agatdalen area (Illokunnguaq, Disko)	Atanikerluk	Not checked
10410	12896-6	*Platanus* sp. cf. *aceroides* Göpp.	Koch 1963	pl. 24, fig. 3	Present	Agatkløft	Agatdal	Correct genus, species unclear
10411	35492-74	*Platanus* sp. cf. *aceroides* Göpp.	Koch 1963	pl. 25, fig. 1	Present	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	Correct genus, species unclear
10412	9241-12	*Platanus* sp. cf. *aceroides* Göpp.	Koch 1963	pl. 26, fig. 1	Not checked	Not from Agatdalen (Tupaussat, southern Nuussuaq)	Quikavsak ?	Not checked
10413	12896-23	*Lauraceaephyllum stenolobatus* Koch	Koch 1963	text-fig. 20; pl. 27, figs 1	Present	Agatkløft	Agatdal	Poss. Lauraceae, aff. *Sassafras*
10414	12896-22	*Lauraceaephyllum stenolobatus* Koch	Koch 1963	pl. 28: fig. 1	Present	Agatkløft	Agatdal	Poss. Lauraceae, aff. *Sassafras*
10415	12896-80	*Lauraceaephyllum stenolobatus* Koch	Koch 1963	pl. 29, fig. 1	Present	Agatkløft	Agatdal	Poss. Lauraceae, aff. *Sassafras*
10416	12896-57	*Lauraceaephyllum stenolobatus* Koch	Koch 1963	pl. 29, fig. 2	Present	Agatkløft	Agatdal	Poss. Lauraceae, aff. *Sassafras*
10417	12896-21	*Lauraceaephyllum stenolobatus* Koch	Koch 1963	pl. 29, fig. 3	Present	Agatkløft	Agatdal	Poss. Lauraceae, aff. *Sassafras*
10418	12896-20	*Lauraceaephyllum stenolobatus* Koch	Koch 1963	pl. 29, fig. 4	Present	Agatkløft	Agatdal	Poss. Lauraceae, aff. *Sassafras*
10419	35492-44	*Lauraceaephyllum stenolobatus* Koch	Koch 1963	pl. 30, fig. 1	Present	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	Poss. Lauraceae, aff. *Sassafras*
10420	12896-86	*Lauraceaephyllum stenolobatus* Koch	Koch 1963	pl. 30, fig. 2	Present	Agatkløft	Agatdal	Poss. Lauraceae, aff. *Sassafras*
10421	12896-24	cf. *Vitis olriki* Heer	Koch 1963	pl. 30, fig. 3	Present	Agatkløft	Agatdal	Correct genus, species unclear
6923		*Vitis olriki* Heer	Koch 1963	pl. 32, fig. 1	Not checked	Not from Agatdalen area (Atanikerluk, south coast of Nuussuaq)	Quikavsak ?	Not checked
10422	12896-30	cf. *Amicia* sp.	Koch 1963	pl. 33, fig. 1	Present	Agatkløft	Agatdal	Uncertain
10423	12896-6	cf. *Amicia* sp.	Koch 1963	pl. 33, fig. 2	Missing	Agatkløft	Agatdal	Uncertain
10424	12896-49	cf. *Rhododendron* sp.	Koch 1963	pl. 34, figs 1, 2	Present	Agatkløft	Agatdal	Uncertain
10425	12896-130	cf. *Rhododendron* sp.	Koch 1963	pl. 34, fig. 3	Present	Agatkløft	Agatdal	Uncertain
10426	15774	cf. *Rhododendron* sp.	Koch 1963	pl. 34, figs 4, 5	Present	Not from Agatdalen area (Atanikerluk, south coast of Nuussuaq)	Agatdal or Eqalulik	Uncertain
?	35492-46	*Dicotylophyllum bellum* (Heer) Seward & Conw.	Koch 1963	pl. 35, fig. 1	Missing	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	Revised: *Platanus bella*
10427	12896-131	*Dicotylophyllum bellum* (Heer) Seward & Conw.	Koch 1963	pl. 35, fig. 2	Present	Agatkløft	Agatdal	Revised: *Platanus bella*
10428	35492-49	*Dicotylophyllum bellum* (Heer) Seward & Conw.	Koch 1963	pl. 36, fig. 1	Present	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	Revised: *Platanus bella*
?	35492-24	*Dicotylophyllum bellum* (Heer) Seward & Conw.	Koch 1963	pl. 36, fig. 2	Present	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	Revised: *Platanus bella*
?	12896-141	*Dicotylophyllum bellum* (Heer) Seward & Conw.	Koch 1963	pl. 36, fig. 3	Missing	Agatkløft	Agatdal	Revised: *Platanus bella*
10430	12896-41	*Dicotylophyllum bellum* (Heer) Seward & Conw.	Koch 1963	pl. 36, fig. 4	Present	Agatkløft	Agatdal	Revised: *Platanus bella*
10431	28955-7	*Dicotylophyllum bellum* (Heer) Seward & Conw.	Koch 1963	pl. 37, figs 1, 2	Present	Qaarsutjægerdal, Big section	Agatdal	Revised: *Platanus bella*
10432		*Dicotylophyllum bellum* (Heer) Seward & Conw.	Koch 1963	pl. 37, fig. 3	Not checked	Not from Agatdalen area (Atanikerluk, south coast of Nuussuaq)	Quikavsak ?	Not checked
6257		*Dicotylophyllum bellum* (Heer) Seward & Conw.	Koch 1963	pl. 37, fig. 4	Not checked	Not from Agatdalen area (Atanikerluk, south coast of Nuussuaq)	Quikavsak ?	Not checked
10433	35492-31	*Dicotylophyllum eridani* (Heer) Koch	Koch 1963	pl. 38, fig. 1	Present	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	→ Juglandaceae (?)
10434	35492-30	*Dicotylophyllum eridani* (Heer) Koch	Koch 1963	pl. 38, fig. 2	Present	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	→ Juglandaceae (?)
10435	35492-29	*Dicotylophyllum eridani* (Heer) Koch	Koch 1963	pl. 38, figs 3, 4	Present	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	→ Juglandaceae (?)
10436	35492-53	*Dicotylophyllum scottii* (Heer) Koch	Koch 1963	pl. 39, fig. 1	Present	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	Revised: *Platanus bella*
10437	35492-40	*Dicotylophyllum scottii* (Heer) Koch	Koch 1963	pl. 39, fig. 2	Present	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	Revised: *Platanus bella*
10438	35492-42	*Dicotylophyllum scottii* (Heer) Koch	Koch 1963	pl. 39, fig. 3	Present	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	Revised: *Platanus bella*
6273		*Dicotylophyllum scottii* (Heer) Koch	Koch 1963	pl. 40, fig. 1	Not checked	Not from Agatdalen area (Atanikerluk, south coast of Nuussuaq)	Quikavsak ?	Not checked
10439	35579-1	*Dicotylophyllum steenstrupianum* (Heer) Seward & Conw.	Koch 1963	pl. 40, fig. 2; pl. 41, fig. 2	Present	Qaarsutjægerdal, Big section	Agatdal	Affiliation unclear
6900		*Dicotylophyllum steenstrupianum* (Heer) Seward & Conw.	Koch 1963	pl. 40, fig. 3; pl. 41, fig. 1	Not checked	Not from Agatdalen area (Atanikerluk, south coast of Nuussuaq)	Quikavsak ?	Not checked
10440	12896-8	*Macclintockia kanei* (Heer) Seward & Conw.	Koch 1963	pl. 42, fig. 1	Present	Agatkløft	Agatdal	Revised: *Macclintockia kanei*
10441	12896-90	*Macclintockia kanei* (Heer) Seward & Conw.	Koch 1963	pl. 42, fig. 2	Present	Agatkløft	Agatdal	Revised: *Macclintockia kanei*
10442	12896-2	*Macclintockia kanei* (Heer) Seward & Conw.	Koch 1963	pl. 42, fig. 3	Present	Agatkløft	Agatdal	Revised: *Macclintockia kanei*
10443	12896-1	*Macclintockia kanei* (Heer) Seward & Conw.	Koch 1963	pl. 43, fig. 1	Present	Agatkløft	Agatdal	Revised: *Macclintockia kanei*

Table 2. Plant fossils described by Koch (1963, 1972a, b) – continued

Mus. nr.	Field nr.	Taxonomic affiliation according Koch*	Published in	Figured in	Status in collection	Locality	Formation	Notes on taxonomy
10444	12896-143	*Macclintockia kanei* (Heer) Seward & Conw.	Koch 1963	pl. 44, fig. 1	Present	Agatkløft	Agatdal	Revised: *Macclintockia kanei*
10445		*Macclintockia kanei* (Heer) Seward & Conw.	Koch 1963	pl. 44, fig. 2	Present	Not from Agatdalen area (Kingittoq, southern Nuussuaq)	Atane ?	Revised: *Macclintockia kanei*
10446	4359-70	*Macclintockia kanei* (Heer) Seward & Conw.	Koch 1963	pl. 44, fig. 3	Not checked	Not from Agatdalen area (Atanikerluk, south coast of Nuussuaq)	Quikavsak ?	Revised: *Macclintockia kanei*
10447	8171	*Macclintockia kanei* (Heer) Seward & Conw.	Koch 1963	pl. 44, fig. 4	Present	Qaarsutjægerdal, Big section	Agatdal	Revised: *Macclintockia kanei*
10448	35492-63	*Macclintockia lyalli* Heer	Koch 1963	pl. 45, figs 1, 3	Missing	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	Revised: *Macclintockia kanei*
10449	35492-62	*Macclintockia lyalli* Heer	Koch 1963	pl. 45, fig. 2	Present	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	Revised: *Macclintockia kanei*
10450	12896-173	*Macclintockia lyalli* Heer	Koch 1963	pl. 45, fig. 4	Present	Agatkløft	Agatdal	Revised: *Macclintockia kanei*
10451	12896-125	*Macclintockia lyalli* Heer	Koch 1963	pl. 46, fig. 1	Present	Agatkløft	Agatdal	Revised: *Macclintockia kanei*
10452	12896-101	*Macclintockia lyalli* Heer	Koch 1963	pl. 46, fig. 2	Present	Agatkløft	Agatdal	Revised: *Macclintockia kanei*
10453	1876-2623	*Macclintockia lyalli* Heer	Koch 1963	pl. 46, fig. 3	Not checked	Not from Agatdalen area (Qullissat, Disko)	Atane	Revised: *Macclintockia kanei*
10454	12896-12	*Macclintockia dentata* Heer	Koch 1963	pl. 47, fig. 1	Missing	Agatkløft	Agatdal	Revised: *Macclintockia kanei*
10455	12896-14	*Macclintockia dentata* Heer	Koch 1963	pl. 47, fig. 2	Present	Agatkløft	Agatdal	Revised: *Macclintockia kanei*
10456	12896-188	*Nordenskioldia borealis* Heer	Koch 1963	pl. 47, fig. 3	Present	Agatkløft	Agatdal	Probably correct
10457	35492-58	*Credneria spectabilis* (Heer) Koch	Koch 1963	pl. 48, fig. 1	Present	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	Platanaceae or Hamamelidaceae
10458	35492-57	*Credneria spectabilis* (Heer) Koch	Koch 1963	pl. 48, fig. 2	Present	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	Platanaceae or Hamamelidaceae
10459	35492-151	*Credneria spectabilis* (Heer) Koch	Koch 1963	pl. 49, figs 1, 2	Present	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	Platanaceae or Hamamelidaceae
10460	12896-31	*Credneria spectabilis* (Heer) Koch	Koch 1963	pl. 50, fig. 1	Present	Agatkløft	Agatdal	Platanaceae or Hamamelidaceae
6569		*Credneria spectabilis* (Heer) Koch	Koch 1963	pl. 50, fig. 2	Not checked	Not from Agatdalen area (Aamaruutissaa, Hareøen/ Qeqertasuatsiaq)	Hareøen	Not checked
6940		*Credneria spectabilis* (Heer) Koch	Koch 1963	pl. 51, fig. 1	Not checked	Not from Agatdalen area (Atanikerluk, south coast of Nuussuaq)	Quikavsak ?	Not checked
10461	35492-134	*Quercus drymeia* Unger-like MT	Koch 1963	pl. 51, fig. 2	Present	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	→ *Eotrigonobalanus* (?)
10462	28955-26	*Quercus drymeia* Unger-like MT	Koch 1963	pl. 51, fig. 3	Present	Qaarsutjægerdal, Big section	Agatdal	→ *Eotrigonobalanus* (?)
10463	12896-105	*Carpinus grandis* Unger-like MT	Koch 1963	pl. 52, fig. 1	Present	Agatkløft	Agatdal	Betulaceae, generic affiliation unclear
10466	35492-130	*Cornus ferox* Unger-like MT	Koch 1963	pl. 52, fig. 2	Present	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	Uncertain
10464	12896-127	*Carpinus grandis* Unger-like MT	Koch 1963	pl. 52, fig. 3	Present	Agatkløft	Agatdal	Betulaceae, generic affiliation unclear
10465	12896-87	*Carpinus grandis* Unger-like MT	Koch 1963	pl. 52, fig. 4	Present	Agatkløft	Agatdal	Betulaceae, generic affiliation unclear
10467	35492-129	*Cornus ferox* Unger-like MT	Koch 1963	pl. 52, fig. 5	Present	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	Uncertain
10468	29759-22	*Magnolia inglefieldi* Heer-like MT	Koch 1963	pl. 53, fig. 1	Not checked	Not from Agatdalen area (Paatuut, southern Nuussuaq)	Atane	Not checked
10469	12896-268	„Salicoide"	Koch 1963	pl. 53, fig. 2	Present	Agatkløft	Agatdal	Uncertain
10470	12896-43	„Salicoide"	Koch 1963	pl. 53, fig. 3	Missing	Agatkløft	Agatdal	Uncertain
10471	35577	*Magnolia inglefieldi* Heer-like MT	Koch 1963	pl. 53, fig. 4	Present	Qaarsutjægerdal, Big section	Agatdal	Possibly correct
10472	12896-211	*Quercus ravniana* Heer-like MT	Koch 1963	pl. 54, fig. 1	Present	Agatkløft	Agatdal	Affiliation unclear
10473	12896-107	Undetermined specimen	Koch 1963	pl. 54, fig. 2	Present	Agatkløft	Agatdal	Uncertain
10474	12896-267	Undetermined specimen	Koch 1963	pl. 54, fig. 3	Present	Agatkløft	Agatdal	Uncertain
10475	35492-36	*Quercus lyelli* Heer-like MT	Koch 1963	pl. 55, fig. 1	Present	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	Affiliation unclear
10476	35492-156	*Quercus laharpii* Gaud.-like MT	Koch 1963	pl. 55, fig. 2	Present	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	Affiliation unclear
10477	28955-2	*Alnus kefersteini* Göpp.-like MT	Koch 1963	pl. 55, fig. 3	Present	Qaarsutjægerdal, Big section	Agatdal	Betulaceae, generic affiliation unclear
10478	12896-156	Undetermined specimen	Koch 1963	text-fig. 5	Missing	Agatkløft	Agatdal	Uncertain
10479	12896-11	Undetermined specimen	Koch 1963	text-fig. 6	Missing	Agatkløft	Agatdal	Uncertain
10480	35492-7	*Metasequoia occidentalis* (Newb.) Chaney	Koch 1963	text-fig. 8	Present	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	Valid
10481	35492-11	*Metasequoia occidentalis* (Newb.) Chaney	Koch 1963	text-fig. 10	Present	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	Valid
10482	29759-22	*Metasequoia occidentalis* (Newb.) Chaney	Koch 1963	text-fig. 11	Missing	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	Valid
10483	4359-169	*Metasequoia occidentalis* (Newb.) Chaney	Koch 1963	text-fig. 12	Not checked	Not from Agatdalen area (Atanikerluk, south coast of Nuussuaq)	Quikavsak ?	Not checked
10484	12896-98	*Lauraceaephyllum stenolobatus* Koch	Koch 1963	text-fig. 22	Present	Agatkløft	Agatdal	Poss. Lauraceae, aff. *Sassafras*
10485	12896-132	*Betula brongniarti* Ettingsh.-like MT	Koch 1963	text-fig. 27	Present	Agatkløft	Agatdal	Betulaceae, generic affiliation unclear
20522	11705-1	*Rosenkrantzia picrodendroides* Koch	Koch 1972a	pl. 1, fig. 1A–C	Present	Turritellakløft, Scaphitesnæsen	Agatdal	Affiliation unclear
20523	8174-1	*Rosenkrantzia picrodendroides* Koch	Koch 1972a	pl. 1, fig. 2	Present	Qaarsutjægerdal, Big section	Agatdal	Affiliation unclear
20524	11705-11	*Rosenkrantzia picrodendroides* Koch	Koch 1972a	pl. 1, fig. 3A, B	Present	Turritellakløft, Scaphitesnæsen	Agatdal	Affiliation unclear
20525	35264	*Rosenkrantzia picrodendroides* Koch	Koch 1972a	pl. 1, figs 4, 5; pl. 13, fig. 2; pl. 13, fig. 3; pl. 14, fig. 1A–E	Present	Qaarsutjægerdal, Big section	Agatdal	Affiliation unclear
20526	9249-41	*Rosenkrantzia picrodendroides* Koch	Koch 1972a	pl. 2, figs 1A,B, 4; pl. 8, figs 2, 3; pl. 11, figs 1, 3; pl. 17, figs 1, 3; pl. 18, figs 1–3	Present	Turritellakløft, Scaphitesnæsen	Agatdal	Affiliation unclear

Table 2. Plant fossils described by Koch (1963, 1972a, b) – continued

Mus. nr.	Field nr.	Taxonomic affiliation according Koch*	Published in	Figured in	Status in collection	Locality	Formation	Notes on taxonomy
20527	11705-3	*Rosenkrantzia picrodendroides* Koch	Koch 1972a	pl. 2, fig. 2; pl. 3, fig. 1; pl. 9, fig. 1, 3; pl. 10, figs 1, 2; pl. 12, figs 1–3	Present	Turritellakløft, Scaphitesnæsen	Agatdal	Affiliation unclear
20528	9249-14	*Rosenkrantzia picrodendroides* Koch	Koch 1972a	pl. 2, fig. 3; pl. 3, figs 2, 3; pl. 4, figs 1, 2; pl. 6, figs 1, 2; pl. 7, figs 1, 2; pl. 11, fig. 4; pl. 16, figs 1–3, 6	Present	Turritellakløft, Scaphitesnæsen	Agatdal	Affiliation unclear
20529	9249-17	*Rosenkrantzia picrodendroides* Koch	Koch 1972a	pl. 5, figs 1–3; pl. 9, fig. 2; pl. 13, fig. 4; pl. 15, figs 1, 2	Present	Turritellakløft, Scaphitesnæsen	Agatdal	Affiliation unclear
20530	11711-1	*Rosenkrantzia picrodendroides* Koch	Koch 1972a	pl. 10, fig. 3	Present	Qaarsutjægerdal, Big section	Agatdal	Affiliation unclear
20531	9249-30	*Rosenkrantzia picrodendroides* Koch	Koch 1972a	pl. 10, fig. 4; pl. 13, fig. 3	Present	Turritellakløft, Scaphitesnæsen	Agatdal	Affiliation unclear
20532	9249-5	*Rosenkrantzia picrodendroides* Koch	Koch 1972a	pl. 10, fig. 5	Present	Turritellakløft, Scaphitesnæsen	Agatdal	Affiliation unclear
20533	11711-2	*Rosenkrantzia picrodendroides* Koch	Koch 1972a	pl. 10, fig. 6	Present	Qaarsutjægerdal, Big section	Agatdal	Affiliation unclear
20534	9249-22	*Rosenkrantzia picrodendroides* Koch	Koch 1972a	pl. 11, fig. 2; pl. 13, figs 1A-C, 3	Present	Turritellakløft, Scaphitesnæsen	Agatdal	Affiliation unclear
20535	11705-8	*Rosenkrantzia picrodendroides* Koch	Koch 1972a	pl. 13, figs 2, 3	Present	Turritellakløft, Scaphitesnæsen	Agatdal	Affiliation unclear
20536	9249-34	*Rosenkrantzia picrodendroides* Koch	Koch 1972a	pl. 13, figs 2, 3	Present	Turritellakløft, Scaphitesnæsen	Agatdal	Affiliation unclear
20538	9249-39	*Rosenkrantzia picrodendroides* Koch	Koch 1972a	pl. 13, figs 2, 3; pl. 14, fig. 2	Present	Turritellakløft, Scaphitesnæsen	Agatdal	Affiliation unclear
20537	11977-1	*Rosenkrantzia picrodendroides* Koch	Koch 1972a	pl. 13, figs 2, 3	Present	Turritellakløft, Scaphitesnæsen	Agatdal	Affiliation unclear
20539	9249-42	*Rosenkrantzia picrodendroides* Koch	Koch 1972a	pl. 13, fig. 2	Present	Turritellakløft, Scaphitesnæsen	Agatdal	Affiliation unclear
20540	9249-58	*Rosenkrantzia picrodendroides* Koch	Koch 1972a	pl. 14, fig. 3	Present	Turritellakløft, Scaphitesnæsen	Agatdal	Affiliation unclear
20541	9249-31	*Rosenkrantzia picrodendroides* Koch	Koch 1972a	pl. 16, figs 4, 5	Present	Turritellakløft, Scaphitesnæsen	Agatdal	Affiliation unclear
20542	35492-46	*Dicotylophyllum bellum* (Heer) Seward & Conw.	Koch 1972a	pl. 23, fig. 2	Missing	Kangersooq, Quleruarsuup isua	Agatdal or Eqalulik	Revised: *Platanus bella*
20543	s.n.	Indet staminate inflorescence	Koch 1972a	pl. 24, figs 1, 2	Present	Not from Agatdalen area (Atanikerluk, south coast of Nuussuaq)	Quikavsak ?	Not checked
20759	9249-64	*Coryphoides poulseni* Koch	Koch 1972b	pl. 1, figs 1A,B, 8A,B; pl. 4, fig. 3	Present	Turritellakløft, Scaphitesnæsen	Agatdal	Arecaceae, generic affiliation unclear
20755	8177	*Coryphoides poulseni* Koch	Koch 1972b	pl. 1, fig. 2A,B	Present	Agatkløft	Agatdal	Arecaceae, generic affiliation unclear
20756	8179-2	*Coryphoides poulseni* Koch	Koch 1972b	pl. 1, figs 3A,B; pl. 4, fig. 5; pl. 17, fig. 2	Present	Qaarsutjægerdal, Big section	Agatdal	Arecaceae, generic affiliation unclear
20764	9249-70	*Coryphoides poulseni* Koch	Koch 1972b	pl. 1, fig. 4	Present	Turritellakløft, Scaphitesnæsen	Agatdal	Arecaceae, generic affiliation unclear
20758	9249-63	*Coryphoides poulseni* Koch	Koch 1972b	pl. 1, figs 6A,B; pl. 4, fig. 7A,B	Present	Turritellakløft, Scaphitesnæsen	Agatdal	Arecaceae, generic affiliation unclear
20767	28955-42	*Coryphoides poulseni* Koch	Koch 1972b	pl. 1, fig. 7	Present	Qaarsutjægerdal, Big section	Agatdal	Arecaceae, generic affiliation unclear
20757	9249-62	*Coryphoides poulseni* Koch	Koch 1972b	pl. 2, figs 1A,B; pl. 3, fig. 2; pl. 5, fig. 1; pl. 6, figs 1, 2; pl. 7, figs 1, 2; pl. 9, figs 1, 2; pl. 10, figs 1–3; pl. 11, figs 1–3; pl. 13, fig. 2A,B	Present	Turritellakløft, Scaphitesnæsen	Agatdal	Arecaceae, generic affiliation unclear
20763	9249-69	*Coryphoides poulseni* Koch	Koch 1972b	pl. 2, fig. 2A,B; pl. 3, fig. 1; pl. 12, fig. 1	Present	Turritellakløft, Scaphitesnæsen	Agatdal	Arecaceae, generic affiliation unclear
20753	8173-1	*Coryphoides poulseni* Koch	Koch 1972b	pl. 3, fig. 3	Present	Qaarsutjægerdal, Big section	Agatdal	Arecaceae, generic affiliation unclear
20760	9249-65 (sect. 1)	*Coryphoides poulseni* Koch	Koch 1972b	pl. 3, fig. 4A,B; pl. 5, figs 2–3; pl. 8, figs 1, 2; pl. 12, fig. 2; pl. 13, fig. 1	Present	Turritellakløft, Scaphitesnæsen	Agatdal	Arecaceae, generic affiliation unclear
20762	9249-67	*Coryphoides poulseni* Koch	Koch 1972b	pl. 4, fig. 1	Present	Turritellakløft, Scaphitesnæsen	Agatdal	Arecaceae, generic affiliation unclear
20761	9249-66	*Coryphoides poulseni* Koch	Koch 1972b	pl. 4, fig. 2	Present	Turritellakløft, Scaphitesnæsen	Agatdal	Arecaceae, generic affiliation unclear
20765	9249-8	*Coryphoides poulseni* Koch	Koch 1972b	pl. 4, fig. 4	Present	Turritellakløft, Scaphitesnæsen	Agatdal	Arecaceae, generic affiliation unclear
20752	8172-1	Indet.	Koch 1972b	pl. 4, fig. 6A, B	Present	Turritellakløft, Scaphitesnæsen	Agatdal	Uncertain
20766	20166	*Coryphoicarpus globoides*Koch	Koch 1972b	pl. 4, fig. 8A,B; pl. 16, fig. 1A-C; pl. 18, figs 1-3	Present	Not from Agatdalen area (Danienkløft, Tunorsuaq, northern Nuussuaq)	Kangilia	Arecaceae, generic affiliation unclear
20754	8173-4	*Coryphoides poulseni* Koch	Koch 1972b	pl. 7, fig. 3	Present	Qaarsutjægerdal, Big section	Agatdal	Arecaceae, generic affiliation unclear
6264	6264	*Exflabellaria groenlandica* (Heer) Lamotte	Koch 1972b	pl. 17, fig. 1	Missing	Not from Agatdalen area (Atanikerluk, south coast of Nuussuaq)	Quikavsak ?	Not checked

* „cfr" in Koch (1963) equals „cf."; specimens labelled by Koch as „design" (see Koch 1963, p. 20–21, for explanation) treated here as morphotypes (MT)

Fig. 6. Phosphoritic nodules from locality 1 (Agatkløft) from sediments previously assigned to the Sonja Member, and locality 2 (Turritellakløft, Big section) from sediments previously assigned to the Turritellakløft Member

rock, etc.) that is mostly found in the centre of the nodule. The main body of the nodules are mostly composed of extremely fine accumulated (possibly organic) matter. In some cases coarser clastic sediments are part of the main body; these nodules are more brownish in colour. Processing of the nodules (see Grímsson et al. 2011b and Denk et al. 2012 for preparation method) revealed a rich assemblage of marine and terrestrial palynomorphs (Fig. 7). The palynomorphs were investigated both by LM and SEM, using the single-grain technique of Zetter (1989). This technique has proved to be very useful for achieving high taxonomic resolution for fossil pollen and spores (e.g. Grímsson et al. 2011a, 2012,

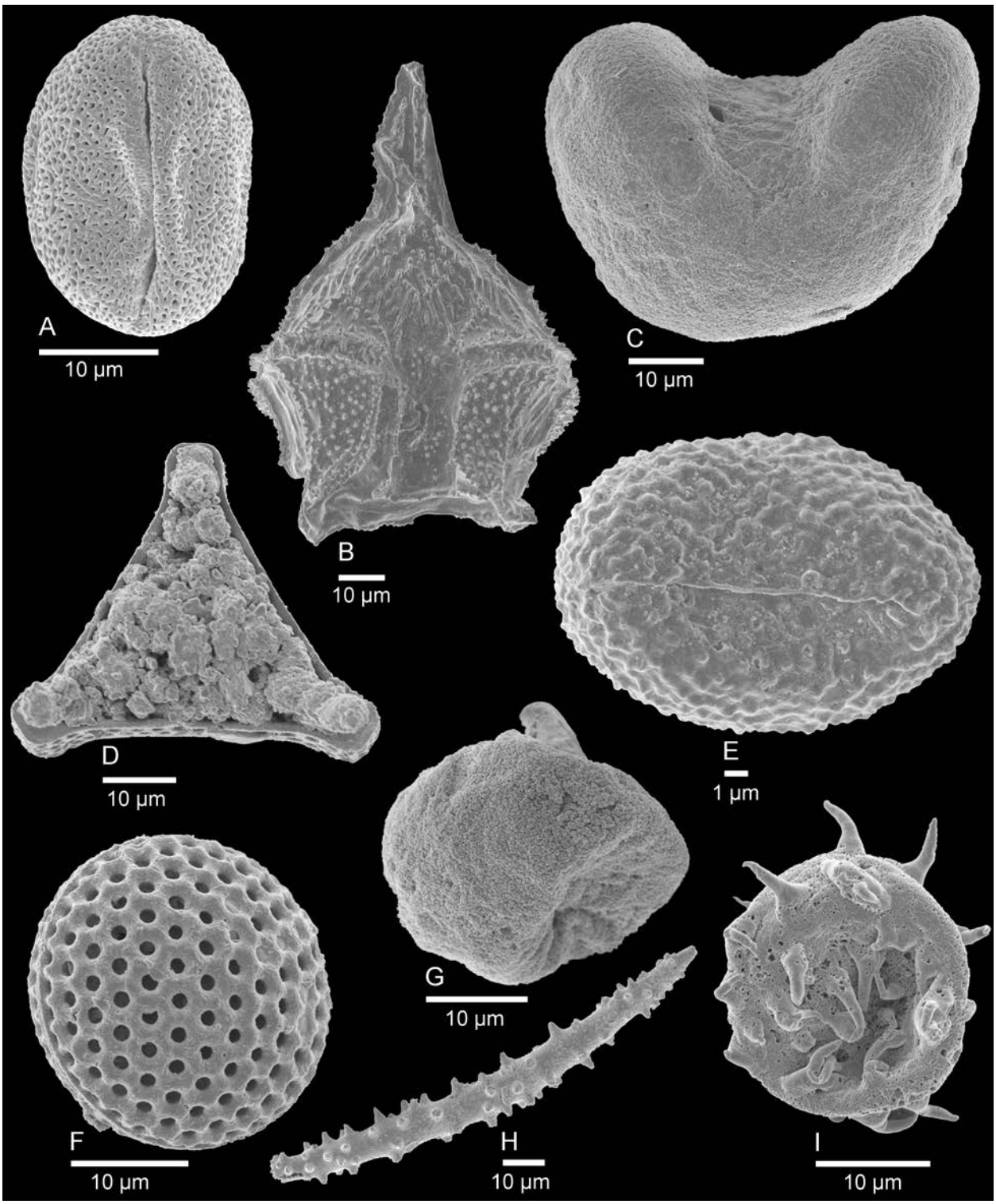

Fig. 7. Selected palynomorphs from the Agatdal Fm preserved in phosphoritic nodules. **A**. Angiosperm pollen. **B**. Marine dinoflagellate. **C**. Bisaccate Pinaceae pollen. **D**. Marine diatom with pyrite crystals. **E**. Monolete Polypodiaceae spore. **F**. Marine diatom. **G**. Papillate Cupressaceae pollen. **H**. Marine sponge spicule. **I** Trilete spore

2014a, 2015a, 2016). Phosphoritic nodules are typically associated with the continental shelves (e.g. Bushinski 1964). Our nodules contain numerous marine palynomorphs (examples shown in Fig. 7B,D,F,H), hence, must have formed in a shallow-marine environment (shelf, coastal seas). The samples resulting from the nodules are extremely rich in organic material, and the preservation of pollen (Fig. 7A,C,G) and spores is excellent (Fig. 7E,I). The palynomorphs must have been fossilised relatively quickly; most are not compacted and either kept or regained their original optimal form after being re-hydrated.

Pollen and other palynomorphs from phosphoritic nodules often have pyrite crystals filling internal cavities (Fig. 7D), visible as black concretions under LM (e.g. Grímsson et al. 2011b). The excellent preservation of palynomorphs from dissolved phosphoritic nodules has only recently been noticed. Pollen and spores from early Oligocene marine phosphoritic nodules were studied from Cospuden in Germany (Schmid 2000, Denk et al. 2012), and from middle Miocene freshwater nodules of Lavanttal in Austria (Grímsson & Zetter 2011, Grímsson et al. 2011b, 2015a, 2016). Preliminary results on the palynoflora from the Agatdal Fm reveal a hyperdiverse angiosperm flora with at least 145 angiosperm pollen types covering a minimum of 34 families. In addition, 25 gymnosperm pollen types (Pinaceae, Cupressaceae, Cycadaceae, Ginkgoaceae, Sciadopityaceae) and 28 different spores have been found so far (Tab. 3)

TAXONOMIC STATUS OF PALAEOCENE PLANT FOSSILS DESCRIBED BY ESKE KOCH IN 1963 AND 1972 FROM THE AGATDALEN AREA (Table 2, Fig. 8)

In his first paper from 1963, Koch figured 147 specimens, mostly leaves assigned to various angiosperms, but also a few conifers and a few fragile fern parts. Some of these fossils have later been revised, others are pending a formal revision.

Table 3. First summary of pollen and spore diversity from phosphoritic nodules of the Agatdal Fm

Group/clade Family	Number of genera/ morphotypes	Group/clade Family	Number of genera/ morphotypes
Monolete spores		**Eudicots (ctd)**	
Polypodiaceae	?/3	**Saxifragales**	
Not yet determined	?/2	Altingiaceae	3/3
Trilete spores		Cercidiphyllaceae	1/1
Gleicheniaceae	1/2	Daphniphyllaceae	1/1
Lycopodiaceae	1/1	Hamamelidaceae	?/9
Osmundaceae	?/4	**Fabids**	
Selaginellaceae	1/1	Fabaceae	1/1
Sphagnaceae	1/4	Betulaceae	3+/8
Not yet determined	?/11	Fagaceae	3+/8
Gymnosperms		Juglandaceae	4+/6
Pinaceae	7/10	Myricaceae	?/5
Cupressaceae	?/10	Normapolles†	?/5
Cycadaceae	?/2	Cannabaceae	1/1
Ginkgoaceae	1/1	Rhamnaceae	1/1
Sciadopityaceae	1/1	Rosaceae	3/3
Not yet determined	1/1	Salicaceae	1/2
Angiosperms		**Malvids**	
Extinct angiosperms	1/2	Amaranthaceae	1/1
Schisandraceae	1/1	Rutaceae	1/1
Not yet determined	?/c. 30	Sapindaceae	?/3
Magnoliids		**Asterids**	
Magnoliaceae	2/2	Clethraceae	1/1
Winteraceae	1/1	Cornaceae	?/8
Monocots (commelinids)		Ericaceae	?/5
Araceae	?/4	**Campanulids**	
Araceae vel Liliaceae	?/2	Adoxaceae	1/1
Liliaceae	?/2	Araliaceae	?/3
Not yet determined	?/5	Chloranthaceae	2/3
Eudicots		**Lamiids**	
Menispermaceae	?/2	Icacinaceae	1/1
Platanaceae	?/6	Oleaceae	1/1
Ranunculaceae	2/2		
Trochodendraceae	1/1		
Vitaceae	2/3		

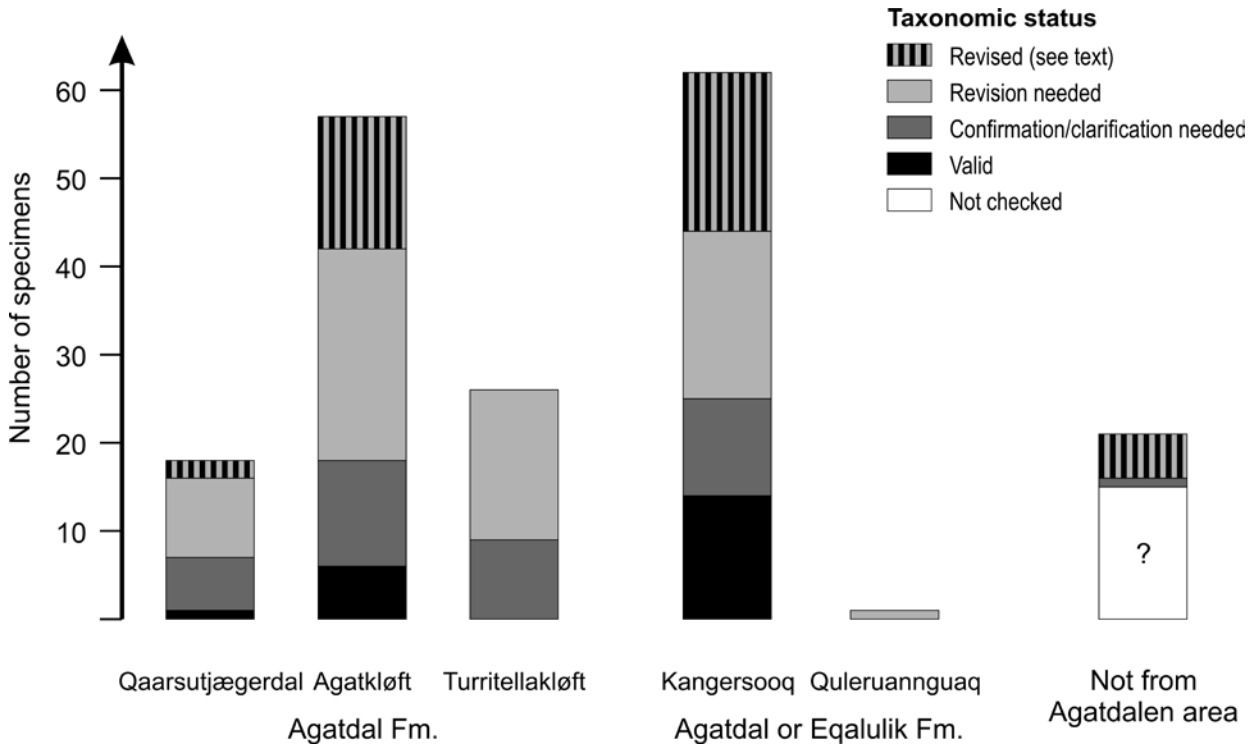

Fig. 8. Bar-chart showing taxonomic status of meso- and macrofossils originally described by Koch (1963, 1972a, b)

The *Cladophlebis groenlandica* fronds are quite characteristic and similar fossils have been described from the Palaeocene of western Greenland (Heer 1883) and the Isle of Mull (Boulter & Kvaček 1989), and the Eocene of Alaska (Hollick 1936), Kamchatka (Budantsev 1997), and northeast Russia (Golovneva 1994) under various different genera. The systematic position of these fossils is uncertain.

The *Hemitelites torelli* material from Agatdalen is very fragmentary. A similar fossil has been figured by Kvaček and Manum (1993, pl. 3, fig. 8, specimen lost) from the Palaeogene of Spitsbergen as Polypodiales gen. et sp. indet. A more detailed affiliation to family or genus is not possible at this time.

The leaves assigned to *Ginkgo adiantoides* certainly belong within that genus, but this species name is typically used for Neogene *Ginkgo* leaves in Europe (e.g. Denk & Velitzelos 2002, Meller et al. 2015). It is uncertain how many species the leaves from Agatdalen and other Palaeocene to Eocene sites in western Greenland, the Faeroe Islands, Spitsbergen, and the British Isles represent. The Palaeocene *Ginkgo gardneri* leaves described by Boulter & Kvaček (1989) from the Isle of Mull are clearly divided into two equal lobes and have a strongly papillate adaxial epidermis, seen in Mesozoic but normally not in Cenozoic ginkgoes. Such epidermal features have not been observed in the bi- to multi-lobed *Ginkgo spitsbergensis* (Manum 1966) from Spitsbergen, a species more similar to the Neogene leaves of *Ginkgo adiantoides*. The Palaeocene material from the Agatdalen (Koch 1963) and the Faeroe Islands (Pott et al. 2014) are multi-lobed, but no cuticle structures have been observed so far in this material. The dispersed fossil *Ginkgo* pollen found in the same sediments as the leaves (F. Grímsson et al., unpublished data) differ not only from each other but also from the pollen affiliated with the typical European Neogene *Ginkgo adiantoides* (Grímsson et al. 2011b). The Palaeogene *Ginkgo* leaves and pollen from this geographical region and North America need to be studied in more detail

Most of the *Metasequoia occidentalis* material from Agatdalen truly belongs to that species. Comparable fossils have been described from, among other sites, the Palaeocene of the Isle of Mull (Boulter & Kvaček 1989) and the Faeroe Islands (Rasmussen & Koch 1963), and the Palaeogene of Spitzbergen (Schweitzer 1974).

The *Quercophyllum groenlandicus* leaf fossils from Agatdalen are very similar to leaves originally assigned to the extinct genus *Fagopsis* described from the late Eocene of Colorado USA (e.g. Manchester & Crane 1983). Therefore, the Agatdalen material was included into *Fagopsis* by Boulter & Kvaček (1989) along with material from the Palaeocene of the Isle of

Mull. Manchester later excluded these leaves from *Fagopsis* and put them within their own genus, *Fagopsiphyllum* (Manchester 1999), based on the observation that the distinctive fruits of *Fagopsis* have never been found in any of the Palaeocene High Artic material from North America, Greenland, and the British Isles. Recently, Bouchal et al. (2014) described the highly characteristic pollen of *Fagopsis* using SEM; the special sculpturing observed in this pollen type has not been documented in any of the Fagaceae pollen from the Palaeocene of Agatdalen (Zetter & Grímsson 2014; this study). The majority of the Fagaceae pollen (ca 8 taxa) are castaneoid-type pollen (Fig. 9B), and no *Quercus*-type pollen was encountered.

The *Quercophyllum furcinervis americana* fossils might indeed belong to Fagaceae, and the morphology of these fossils further

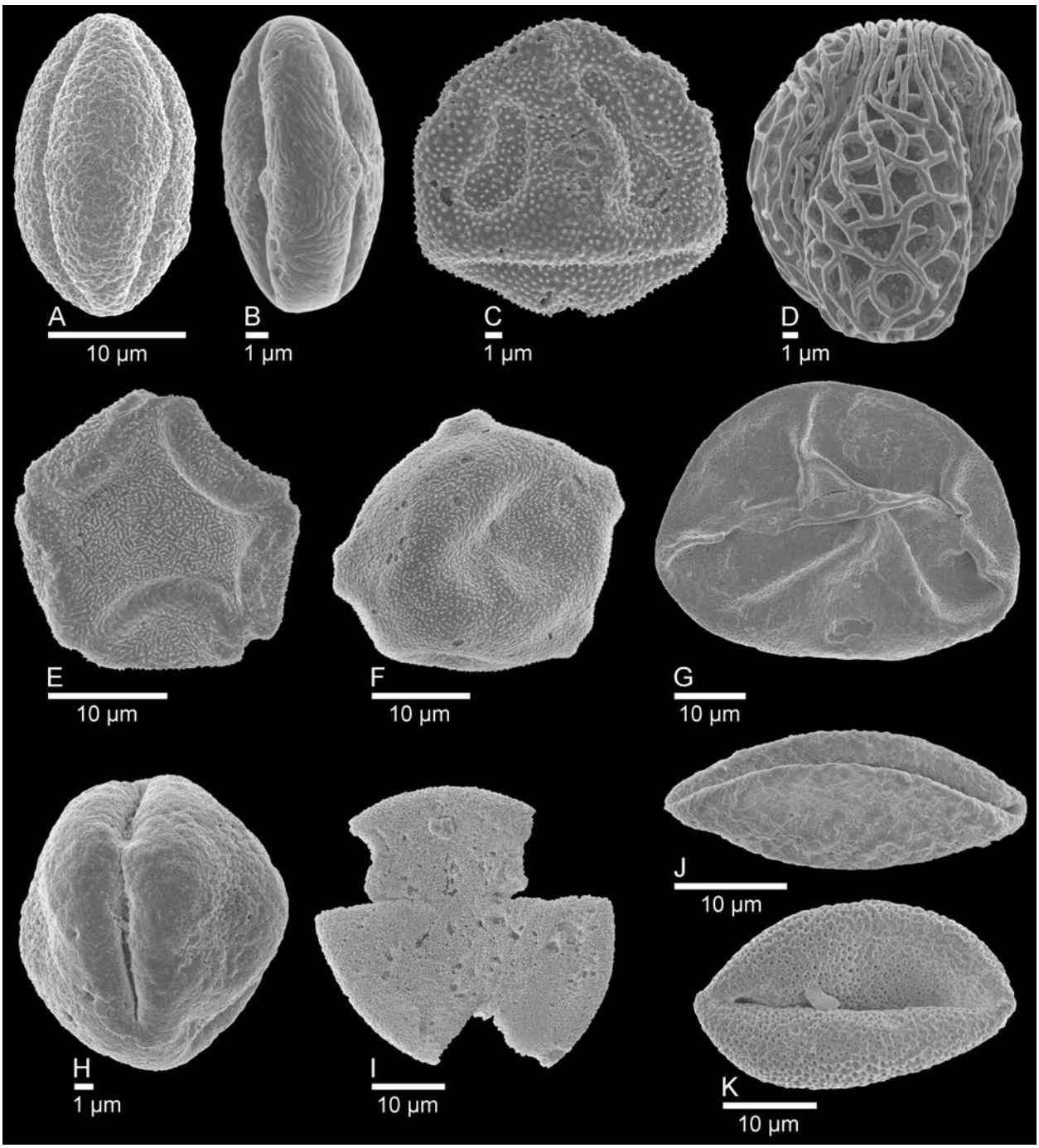

Fig. 9. Selected pollen from the Agatdal Fm (see text). **A**. *Eotrigonobalanus* sp. **B**. Castaneoideae gen. et spec. indet. **C**. Juglandaceae gen. et spec. indet. **D**. Trochodendraceae gen. spec. indet. **E**. *Alnus* sp. **F**. aff. *Carpinus* sp. **G**. Potential *Magnolia* sp. **H**. One of two *Vitis*-type pollen morphs. **I**. Cercidiphyllaceae gen. et. spec. indet. **J**. *Liriodendron* sp. **K**. Palm pollen (Arecaceae gen. et spec. indet)

suggests that some of them could belong to the genus *Eotrigonobalanus*. *Eotrigonobalanus* pollen grains are very characteristic and easy to identify (e.g. Walther & Zetter 1993, Denk et al. 2012) and can be found in the phosphoritic nodules of the Agatdal Fm (Fig. 9A) as well as in the younger Eocene western Greenland sediments of Qeqertarsuatsiaq (Hareøen; Grímsson et al. 2015b). Some or all of the *Cupuliferites angmartusuticus* and *Quercus drymeia*-type fossils could also fall within this *Eotrigonobalanus* leaf morphotype. Still, some of the fossils might also signify other Fagaceae, the castaneoids, since pollen representing that group is the most common Fagaceae pollen observed in the sediments of the Agatdal Formation. The *Dryophyllum* cf. *subfalcatum* leaf fossil also has affinities to the castaneoids. All the Fagaceae-like leaf fossils from the Agatdalen area need to be re-studied in more detail and in relation to the dispersed Fagaceae pollen record to fully reveal the taxonomic relationship of individual specimens.

The cf. *Populus* sp. leaf from Agatdalen is too badly preserved and lacking large parts to be affiliated with any certainty to a family or genus, but the general venation is Betulaceae-like.

The *Juglandiphyllum denticulatum*, *Dicotylophyllum bellum*, and *Dicotylophyllum scottii* specimens all seem to represent the same morphotype. Leaves showing this morphology have been treated as Platanaceae (*Platanus bella*) by Kvaček et al. (2001), including leaves from the Palaeocene of western Greenland, Wyoming (USA), and northwestern China.

The taxonomic position of the cf. *Liriodendron* sp. leaf is uncertain, but pollen similar to that of modern *Liriodendron* can be found in the Agatdalen material (Fig. 9J).

The *Cercidiphyllum arcticum* type leaves co-occur with both the typical *Nyssidum* (Cercidiphyllaceae) and the *Nordenskioldia* (Trochodendraceae) type fruits in the Agatdalen area. Also, pollen of Trochodendraceae and Cercidiphyllaceae has been observed in these sediments (Zetter & Grímsson 2014; work in progress), with the former being much more abundant. If the leaves originate from the same species (or group of species) as the *Nyssidum* fruits and are affiliated with the Cercidiphyllaceae-type pollen (Fig. 9I), they could possibly be included in the genus *Trochodendroides* (e.g. Crane 1984). If the leaves were produced by the same plant as the *Nordenskioldia borealis* fruit, they could be affiliated with the Trochodendraceae-type pollen (Fig. 9D) and possibly included in the genus *Zizyphoides* (e.g. Crane et al. 1991). The fruits may well represent the two families; the presence of only one leaf type also may simply indicate that one plant grew closer to the depositional area than the other, while fruits of both may have been transported by water. The basic form and leaf margins of the Agatdalen fossils show that they are much more similar to leaves of *Trochodendroides* than *Zizyphoides*. A more detailed study of each individual leaf fossil is needed to clarify if this morphogroup is composed of different species or not.

The *Corylopsiphyllum groenlandicum* leaves were convincingly affiliated with *Corylopsis* (Hamamelidaceae) by Koch (1963, p. 50–53). A similar but very small leaf has been described from the early Eocene Republic flora, USA (Radtke et al. 2005) as *Corylopsis*.

The *Platanus* sp. cf. *aceroides* fruit seems to be a Platanaceae, but the specimen is currently missing so further analyses/confirmation were not possible. The leaf part referred to the same taxon is apparently affiliated to the correct genus.

The *Lauraceaephyllum stenolobatus* leaves are distinct in shape and bear similarities to recent and fossil *Sassafras* foliage, and therefore are most likely Lauraceae. Leaves of this type have also been documented from the Palaeocene of England and France (summarised in Kvaček 2010).

It is uncertain if the cf. *Vitis olriki* leaf represents that genus. The basic leaf morphology and venation of the fossil can be found in extant *Vitis*, but the fossil leaf was found in sandstone and the margin and higher-order venation are poorly preserved and do not allow exclusion of other generic affinities. Nonetheless, two different *Vitis*-type pollen (Fig. 9H) from the dispersed pollen record show that *Vitis* did grow in the early Palaeocene of western Greenland, but it is unknown if these pollen types originate from the same organism as the leaf fossil.

The cf. *Amicia* sp. leaves are difficult to evaluate. The fossils bear some similarities to leaves of extant *Amicia*, but also with many other, more or less distantly related, modern Fabaceae genera. Leaves with the same basic form are also known from the Cretaceous under various names and placed into different groups (e.g. Seward 1924) .

The cf. *Rhododendron* sp. leaves cannot be affiliated to this genus with certainty and since several plant groups produce similar narrow-elliptic entire margined leaves they might not even belong to the Ericaceae.

The *Dicotylophyllum eridani* leaf fossils are, based on the form and venation, most likely leaflets of Juglandaceae. A partly preserved leaf with a leaflet still attached to the rachis has also been observed. The dispersed pollen record comprises various different extinct and modern Juglandaceae lineages (Zetter & Grímsson 2014; example shown in Fig. 9C) suggesting that this family should also be represented in the macrofossil record.

The single *Dicotylophyllum steenstrupianum* leaf from Agatdalen shows morphological traits found in the Betulaceae, Fagaceae, and Hamamelidaceae. There are different opinions on the appropriate genus affiliation for this type of leaf fossil. Boulter & Kvaček (1989) assigned this particular fossil, along with other Palaeocene West Greenland specimens and fossil leaves from the Palaeogene of the British Isles and Spitsbergen, to the form-genus *Ushia* (as *U. olafsenii*). This genus is based on *Ushia kamyschinensis* from the Palaeocene of Kazakhstan and southern Russia/Lower Volga area (Kolakovskij 1965, Krassilov et al. 1996). Kvaček et al. (1994) and Kvaček & Manum (1997) combined various other leaves from Spitsbergen into *Ushia olafsenii* showing a substantial variation in size and lamina features as compared to the specimens from the British Isles and Greenland. Budantsev & Golovneva (2009) moved the Spitsbergen specimens into the genus *Rarytkinia* (*R. quercifolia*) that was established for latest Cretaceous to early Palaeocene leaf fossils (*R. terechovae*) from the Russian Far East (Golovneva & Abramowa 1990, Golovneva 1994, 2000). The main difference between *Ushia* and *Rarytkinia* is the form of the teeth, but both taxa may be closely related and just reflecting an Arctic vs mid-latitude differentiation pattern (L. Golovneva, pers. comm., 2016): teeth of *Ushia* are curved and sharp, which appears to apply for the Agatdalen fossil, while those of *Rarytkinia* are bluntly triangular. The latter seem to be the case for the fossil with the same name from the contemporaneous Quikavsak Fm (Koch 1963, pl. 40, fig. 3). Since both genera are similar and *Rarytkinia* species are characterised by considerable variability in leaf morphology, a more comprehensive taxonomic treatment of all western Greenland specimens is needed.

The *Macclintockia kanei*, *Macclintockia lyalli*, and *Macclintockia dentata* leaves all overlap in morphology and may represent a single polymorphic species as suggested by Boulter & Kvaček (1989).

The *Credneria spectabilis* leaf fossils seem to represent two different morphotaxa with possible affinities to Platanaceae and Hamamelidaceae, and need to be studied in further detail.

The taxonomic position of the leaf fossils with affinity to Betulaceae (*Carpinus grandis*-type, *Alnus kefersteini*-type, and *Betula brogniarti*-type; Table 2) is uncertain. Koch (1963) thought that these remnants do not relate to a single, discrete species and flagged them as "design". All the leaves do, nevertheless, suggest a relationship with Betulaceae, but assigning them to these particular extant genera is not recommended at this time. There are no convincing *Betula* fossils known from the Palaeocene of the Northern Hemisphere, and we have not found a single *Betula*-type pollen grain so far among the numerous Betulaceae pollen grains extracted from the phosphoritic nodules. *Alnus* pollen grains (Fig. 9E) are numerous and of various types, but so far only a single possible *Carpinus*-type pollen grain (Fig. 9F) has been found. Various other extinct Betulaceae pollen types have also been observed; hence the leaves could belong to some extinct Betulaceae genus.

The *Cornus ferox*-type leaves cannot be affiliated to this extant genus. So far no attempts have been made during this study to place these leaves systematically. Also, in the rich pollen record of the Agatdalen sediments no *Cornus*-type pollen grains have been documented, but *Cornus* pollen is usually easy to identify and is known from other Palaeocene sites (e.g. Manchester et al. 2015).

The *Magnolia inglefieldi*-type leaf might belong to this genus, but the leaf part is poorly preserved and similar venation and margin type is known from various other angiosperm groups. *Magnolia*-type pollen can be found in the Agatdalen sediments (Fig. 9G).

All the oak-affiliated leaves (*Quercus ravniana*-type, *Q. lyelli*-type, and *Q. laharpi*-type) need to be revised. There is no convincing fossil evidence of the genus *Quercus* from the Palaeocene (Grímsson et al. 2015b, fig. 16). These fossils seem to represent different morphotypes

with affiliation to Fagaceae and/or Juglandaceae, and need to be studied in more detail.

In his later papers, Koch figured 37 specimens, mostly fruits and seeds, assigned to three species including two from the Agatdalen area; *Rosenkrantzia picrodendroides* and *Coryphoides poulseni* (Koch 1972a, b).

The *Rosenkrantzia picrodendroides* fruits were suggested by Koch (1972a) to be related to *Picrodendron* (Picrodendraceae). According to S.R. Manchester (pers. comm. 04/2016) the affiliation of these fruits to Picrodendraceae is not convincing. The modern *Picrodendron* fruits that Koch (1972a) illustrated and used for comparison have anticlinal fibers composing the endocarp, but the endocarp in *Rosenkrantzia* fossils appears to be composed of isodiametric sclereids. Also, the fossil compound leaf from Agatdalen suggested by Koch (1972a, pl. 23, fig. 2; addressed as *Dicotylophyllum bellum*) to represent a *Picrodendron*-type leaf has been shown to be a Platanaceae (*Platanus bella*) by Kvaček et al. (2001). Additionally, we have not observed any Picrodendraceae-type pollen grains in the material from Agatdalen, but such pollen is quite characteristic, easy to identify, and currently known from various Eocene sites in Western and Central Europe (Zetter & Hofmann 2008, Zetter et al. 2011). Therefore the family status of these fruits is open to discussion.

The *Coryphoides poulseni* fruits and seeds figured by Koch (1972b) can be convincingly affiliated to Arecaceae, but establishing the generic affiliation needs a more detailed investigation (S.R. Manchester, pers. comm., 04/2016). Rare dispersed palm pollen (Fig. 9K) can be observed in the Agatdalen material.

The taxonomic overview, presented in this section, of previously described macro- and mesofossils from the Palaeocene of the Agatdalen is meant as preliminary results. The fossils will be studied individually in more detail and in relation to the dispersed palynoflora under study.

CONCLUSIONS AND OUTLOOK

In this work, we link the plant fossils stored in the collection of the Geological Museum in Copenhagen (part of the National History Museum of Denmark) and originally described by Koch (1963, 1972a, b) with the newly established lithostratigraphic framework by Dam et al. (2009). Many fossils can be associated with the late Danian (64–62 Ma) Agatdal Fm; most of the rest belong either to the Agatdal Fm or the overlying Equalulik Fm. A few fossils from outside the Agatdalen area come from Late Cretaceous to Eocene formations in western Greenland, the Atane Fm (2 specimens), Kangilia Fm (1), Quikavsak Fm (14), Atanikerluk Fm (3), and Hareøen Fm (1). The phosphoritic nodules found in sediments of the Agatdal Fm, studied here for the first time, revealed a high number and diversity of well-preserved palynomorphs, including a diverse pollen and spore flora. Future papers will be based mostly on high-taxonomic-resolution palynological data (LM, SEM) and will focus on particular taxa (families, genera) and their phylogenetic and palaeophytogeographic importance. When possible, the related macrofossils will be revised. A long-term goal is to correlate environmental proxies from terrestrial palynomorphs and plant macrofossils with those obtained from the marine palynomorphs (from the nodules) and invertebrate fossils (existing publications) and to try to evaluate the Palaeocene environment of western Greenland from shallow marine to inland mountains. In the end, it should be possible to put forward a synthetic hypothesis about the climatic situation in the late Danian of western Greenland.

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