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A new late Palaeogene macro ora from Bellsund, Spitsbergen

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ABSTRACT. New macro ora remains have been described from the terrestrial coal-bearing Skilvika Formation (Calypsostranda Group, late Palaeogene) of Bellsund, Spitsbergen. The plant assemblage is dominated by two genera: *Metasequoia* (Coniferae) and *Trochodendroides* (Trochodendraceae vel Cercidiphyllaceae). Other angiosperms include species of the genera *Platanites* (Platanaceae), *Corylites* (Betulaceae), *Vitiphyllum* (?Vitaceae), other representatives of the families ?Fagaceae, Sapindaceae and Hippocastanaceae, two specifically determined fruits belonging to the genus *Nyssidium* (Cercidiphyllaceae), moreover some Dicotyledones (gen. et sp. div.) and Monocotyledones (Liliopsida, gen. et sp. indet.). The Sphenophyta are represented by the genus *Equisetum*. The macro ora of the Skilvika Formation represents the so-called Polar broad-leaved deciduous forest. It corresponds best to the late Eocene/Oligocene plant assemblage from Brøggerhalvøya of northwest Spitsbergen.

KEY WORDS: macro ora, late Palaeogene, Spitsbergen, Arctic

INTRODUCTION

The presence of plant remains in the Tertiary rocks of Spitsbergen was already known in the 19th century. Heer (1868, 1870, 1876) was the first naturalist to examine and describe them; later on the ora of the region was studied by Nathorst (1910, 1919), while Gothan (1910) determined wood fragments which were found there. Further palaeobotanical studies were carried out in Spitsbergen by Schloemer-Jäger (1958) who described the Palaeogene leaf ora from the Brögger Peninsula, and Schweitzer (1974) who examined conifer remaints of the same age preserved in Spitsbergen deposits. Subsequent palaeobotanical papers were published by Vakulenko and Livshits (1981), Sveshnikova (1975), Zastawniak (1981), Budantsev (1983), Kvaček et al. (1994), and Golovneva (2000, 2002). In addition, palynological studies were conducted on the Spitsbergen deposits by Manum (1962) and studies of the diatoms by Manum and Throndsen (1986). Palynomorphs from a Palaeocene clastic dyke at Janusfjellet, Central Spitsbergen, were determined by Ziembińska-Tworzydło (Wierzbowski & Ziembińska-Tworzydło 1984). A separate publication by Schweitzer (1980) described habitat conditions and climate in the early Tertiary of Spitsbergen.

The late Palaeogene macro ora here described has been collected by the first author in 2002 at Calypsostranda, south Bellsund, central Spitsbergen (Fig. 1). The paper is a contribution to knowledge of Palaeogene oras of Spitsbergen. It refers to an isolated occurrence of Tertiary deposits located westward from the main development of Tertiary strata in the Central Spitsbergen Basin. The fossil plants determined are housed in the Museum of the W. Szafer Institute of Botany, Polish Academy of Sciences in Kraków.

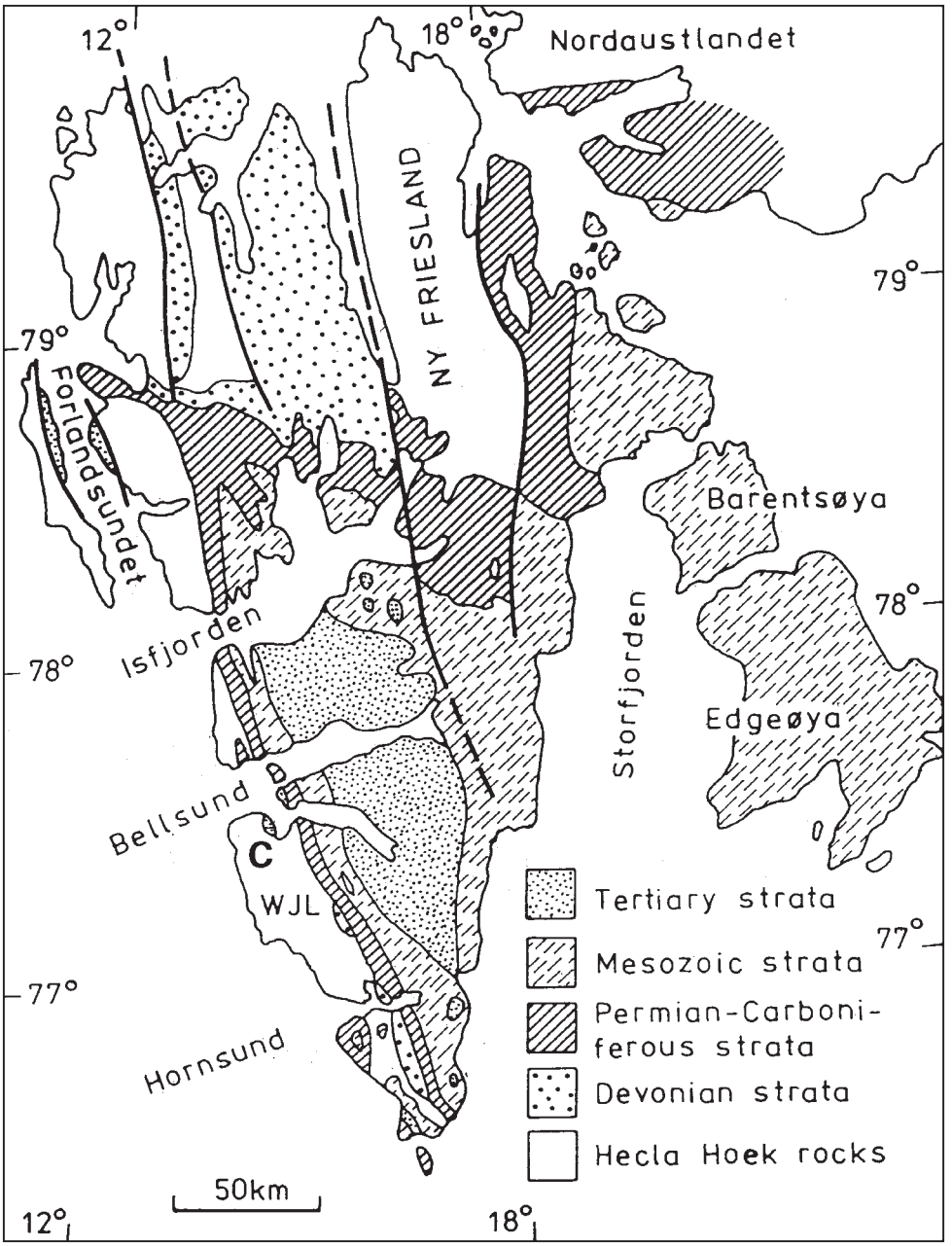

Fig. 1. Simplified geological map of Svalbard (compiled from various sources). **C** – Calypsostranda (Bellsund), **WJL** – Wedel Jarlsberg Land

GEOLOGICAL SETTING

LOCATION AND LITHOSTRATIGRAPHY

The late Palaeogene strata crop out at Calypsostranda between Renardbreen in the south, and Skilvika in the north (Fig. 2). They fill a rather shallow tectonic graben (Calypsostranda Graben) which is a minimum 6 km long and more than 1.5 km wide, its Palaeogene sediment pile exceeding 250 m in thickness. The graben is bounded from the southwest by vertical, NW-SE-directed Calypsostranda Fault, and from the southeast by vertical, NE-SW-directed Josefbukta Fault. The northeastern and northern boundaries of the graben run under sea level at junction of Recherchefjorden and Bellsund (Birkenmajer 2004).

The Tertiary sediment fill of the Calypsostranda Graben, formally distinguished as the Calypsostranda Group, has been subdivided into two formations: the lower Skilvika Formation, about 100 m thick, and the upper Renardodden Formation more than 150 m thick (see Livshits 1967, Dallmann et al. 1990, Harland 1997, Harland et al. 1997, Dallmann 1999).

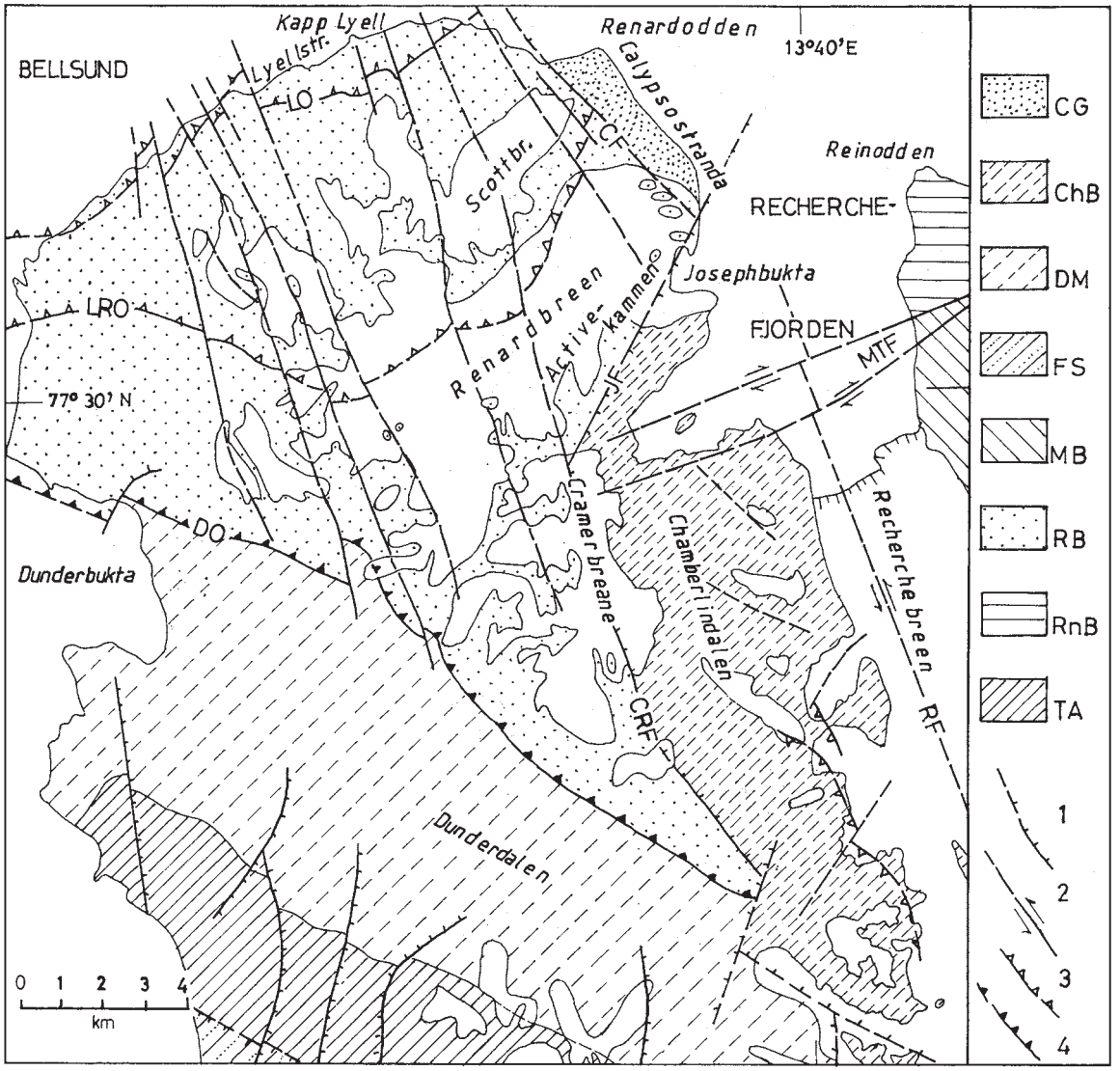

Fig. 2. Major tectonic elements in NW Wedel Jarlsberg Land and location of the Late Palaeogene Calypsostranda Group (reinterpreted from Dallmann et al. 1990, geological map 1:100,000, and supplementged by Birkenmajer 2004, fig. 9). **CG** – Calypsostranda Graben (Tertiary deposits), **ChB** – Chamberlindalen Block (mainly Late Proterozoic rocks), **DM** – Dunderdalen Monocline (Late Proterozoic metasediments), **FS** – Fløysletta Synclinorium (?Middle-?Early Proterozoic metasediments), **MB** – Martinfjella Block (Late Proterozoic-Early Ordovician metasediments), **RB** – Renardbreen Block (Middle-Late Proterozoic metasediments), **RnB** – Reinodden Block (Late Palaeozoic-Mesozoic deposits), **TA** – Thiisfjellet Anticlinorium (Middle Proterozoic rocks), **DO** – Dunderfjellet Overthrust, **LO** – Lyellstranda Overthrust, **LRO** – Lognedalen-Renardbreen Overthrust, **CF** – Calypsostranda Fault, **CrF** – Cramerbreane Fault, **MTF** – Maria-Theresiatoppen Faults, **1** – dip-slip faults (barbs on downthrown side), **2** – strike-slip faults (arrows indicate relative movement directions), **3**, **4** – overthrusts

THE SKILVIKA FORMATION

The Skilvika Formation consists of terrestrial sediments, mainly grey, fine-grained, often laminated sandstones alternating with dark-grey to black shales and coal shales, and with thin black coal seams. Red-weathered sideritic concretions and layers sometimes occur in the shales. Macro oral remains have been found mainly in sandstone beds (mostly angiosperm leaf imprints) and in siderites (mostly conifer shoots).

At Skilvika, the formation rests unconformably directly upon Proterozoic metasediments (Kapp Lyell diamictites). There is a controversy whether the Palaeogene/Proterozoic contact is (i) sedimentary (Vonderbank 1970, Livshits 1974) or (ii) tectonic (Thiedig et al. 1979, Dallmann 1989, Kowallis and Hauser – fide Dallmann 1989, Dallmann et al.1990 and Dallmann 1999, figs 4–49).

The first author prefers the first explanation. According to his observations in 2002, the Proterozoic metasediments (grey, rusty, yellow quartzite clast-supported diamictite – yellow diamictite unit of Birkenmajer 2003)

which occur below the Palaeogene/Proterozoic contact are strongly tectonized (folded and faulted), dipping at angles of up to 60 degrees east, contrary to the overlying terrestrial Skilvika Formation strata which uniformly dip at 30–40 degrees east. The Skilvika Formation begins with a 2-m thick bed of rather chaotic basal breccia ('Rochesterpynten Formation' of Harland et al. 1993, p. 100, and Harland 1997, p. 180) consisting in the upper part of grey, laminated, angular sandstone fragments and blocks (5–20 cm across) suspended in sandy matrix, and in the lower part – of angular fragments (1–5 cm across) derived from the underlying diamictite. This basal breccia could be regarded as a fossilized incipient slump.

There follows a regular sequence of grey, fine-grained, often laminated sandstones alternating with grey to black shales, coalshales and thin coal seams – a typical uvio-deltaic to lacustrine development of the Skilvika Formation.

Main exposures. Between Skilvika (in the north) and Renardbreen (in the south) there are five main exposures of the Skilvika Formation (Fig. 3).

(A) **Skilvika-Renardodden**, marine cliff section (**sites 29, 30, 35**). This is the best and most complete section of the Skilvika Formation (type section). The formation is here more than 100 m thick, consisting mainly of grey to black fine-grained and laminated sandstone beds alternating with grey shale, clayshale and coalshale, with thin horizons of black shaly coal. This section yielded the majority of plant fossils recorded by previous authors (cf. Thiedig et al. 1979, fig. 3, Dallmann 1999, figs 4–49).

(B) **Rensdyrbekken** (informal name, meaning: Reindeer stream), **site 26**: a rather poor exposure of the Skilvika Formation in stream bed. The strata dip 5–10 degrees northeast. A tentative cross-section is given in Fig. 4A. Layers numbered from top downwards.

Layer No.	Thickness (m)
(1) Shale, grey, with thin coal seam	>3
(2) Sandstone, soft, grey	2–3
(3) Shale, grey, with thin coal seam	2–3
(4) Sandstone, rusty, with plant-bearing siderite (10 cm) at top	2–3
(5) Shale, grey, with thin coal seam	>1

(C) **Calypsobyen**, **site 22**, an abandoned coal-mine, with traces of six collapsed shafts, and with several dump-heaps. A poor exposure of grey, yellowish-weathered soft sandstone, dipping 20° NE, is visible in a ravine south of the mining site (Fig. 3). Rock fragments of the Skilvika Formation in dump heaps consist of grey and yellowish-weathered medium-grained sandstone, black coalshale and black coal. No macroscopic plant remains have been collected.

(D) **Tyvjobekken** (informal name, meaning Arctic skua stream), **sites 8, 12–14** (Figs 3, 4B).

Site 8 (upper part of the creek, poor exposure – scree): Fragmented green, platy, fine-grained sandstone (with cementation concretions 2–3 cm in diameter), moreover fragments of fine sedimentary breccia consisting of small pellets (0.1–1 cm) of green shale (pellet conglomerate) or green phyllite. This is the lowest part of the Skilvika Formation situated very close to the Calypsostranda Fault and an exposure of the Kapp Lyell diamictite (see Fig. 3).

Site 12 (outlet of Tyvjobekken): North of the hut, traces of an old shaft, and a dump heap with pieces of coal are still visible. Another shaft was probably located in front of the hut.

Site 13 (middle part of Tyvjobekken): Large loose blocks of green fine-grained sandstone.

Site 14 (upper part of Tyvjobekken – Fig. 4B), section of northern slope of the valley (layers numbered from the top – downwards). The beds dip 25° ESE:

Layer No.	Thickness (m)
(1) Sandstone and shale, black and dark-grey with one coal seam (5–10 cm)	1–2
(2) Sandstone, fine-grained, unevenly bedded, grey	4
(3) Shale, grey to black, with streaks of black coal (1–2 cm)	2.5
(4) Sandstones, medium to fine-grained, unevenly bedded, grey to yellow-green, alternating with black to grey shale. A plant-bearing horizon (rusty-weathered sandstone band 0.2–0.3 m thick) occurs in upper part of the unit. Plant fossils have mainly been collected from loose blocks of finely-rippled sandstone	>5
(5) Coalshale, black, with streaks of coal 2–5 cm thick, with siderite concretions up to 20 cm thick in upper part	>5
(6–11) Sandstones, grey (layers 6, 8, 10), alternating with dark-grey to black shales with thin (1–5 cm) coal streaks (layers 7, 9, 11)	>35

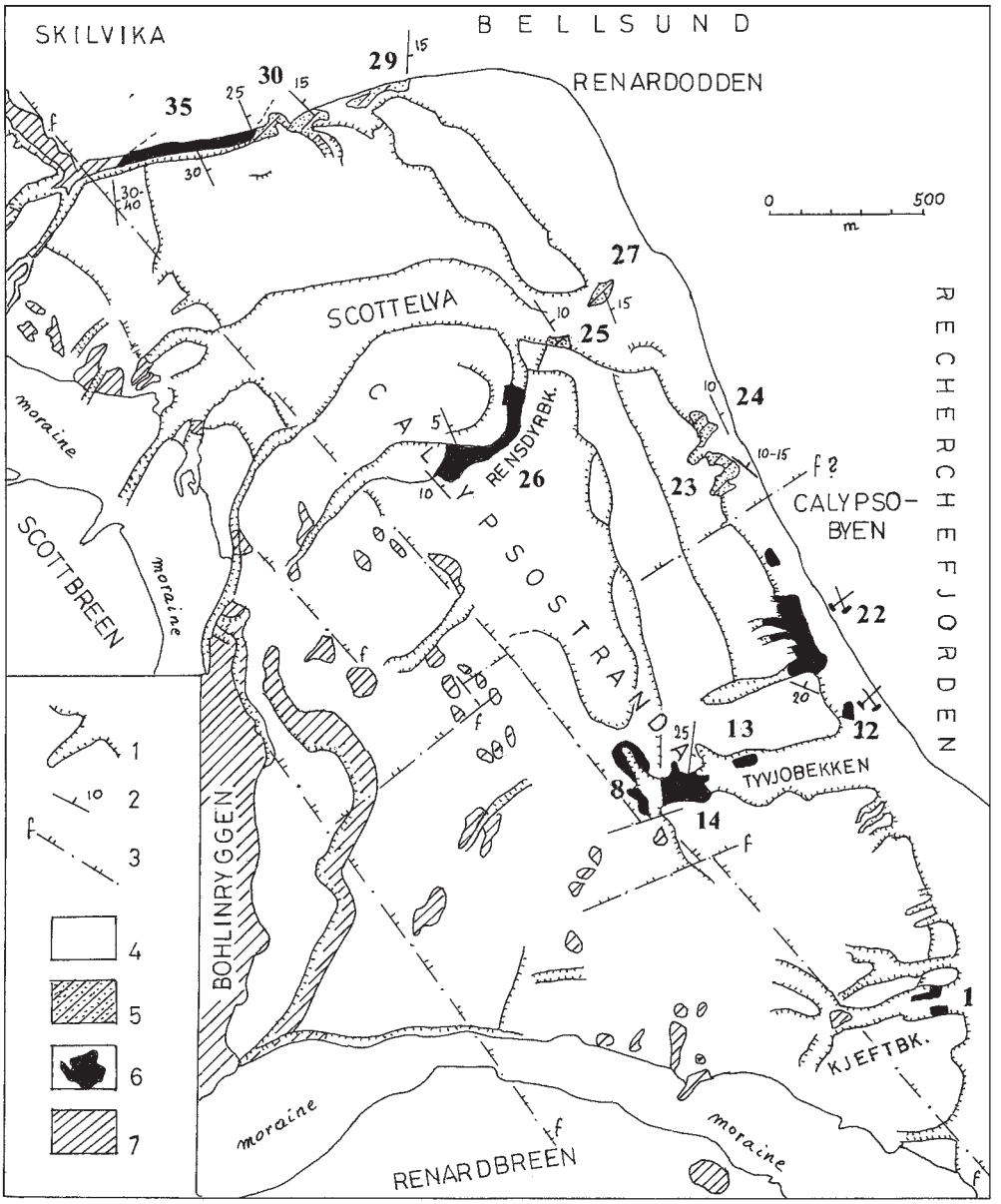

Fig. 3. Exposures (**A-E**) of Palaeogene strata at Calypsostranda between Skilvika-Renardodden and Josefbukta. **1** – Quaternary cover, **2** – Skilvika Fm. (Palaeogene), **3** – Renardodden Formation (Palaeogene), **4** – Proterozoic metasediments, **5** – dips of Palaeogene strata, **6** – faults, **7** – erosional escarpments. Bold numbers denote field sampling sites

(E) **Kjeftbekken** (informal name: a human jawbone was found there), **site 1** (Fig. 3). Black shale fragments are visible in slope scree. Probably, this is the southernmost site of Tertiary deposits at Calypsostranda.

THE RENARDODDEN FORMATION

The Renardodden Formation (Fig. 3: Sites 23–25, 27, 29, 30) directly follows the Skilvika Formation, as is well visible in the cliff section between Skilvika and Renardodden (see Figs 2, 3: site 30). This is a sequence of shallow marine strata over 150 m thick (see Dallmann 1990, fig. 4–49). It starts with massive grey-greenish rippled sandstone layers (with *Scolithos*-type vertical burrows) containing coal detritus and streaks of reworked black coal. The sandstones alternate with dark shale, and contain one sandy gravel bed (conglomrate) consisting mainly of quartzite pebbles.

Higher up, there follow bluish-grey to grey, banded, often concretionary, rather soft (easily weathering) fine-grained sandstones in layers 10–50 cm thick, with thin intercalations of medium- to coarse sandstone. The beds, locally rich in trace fossils *Ophiomorpha* (resp. *Thalassinoides*-type crab burrows), dip 10–15° NE. Well-rounded quartz and quartzite gravel (0.5–3 cm, occasionally up to 10 cm

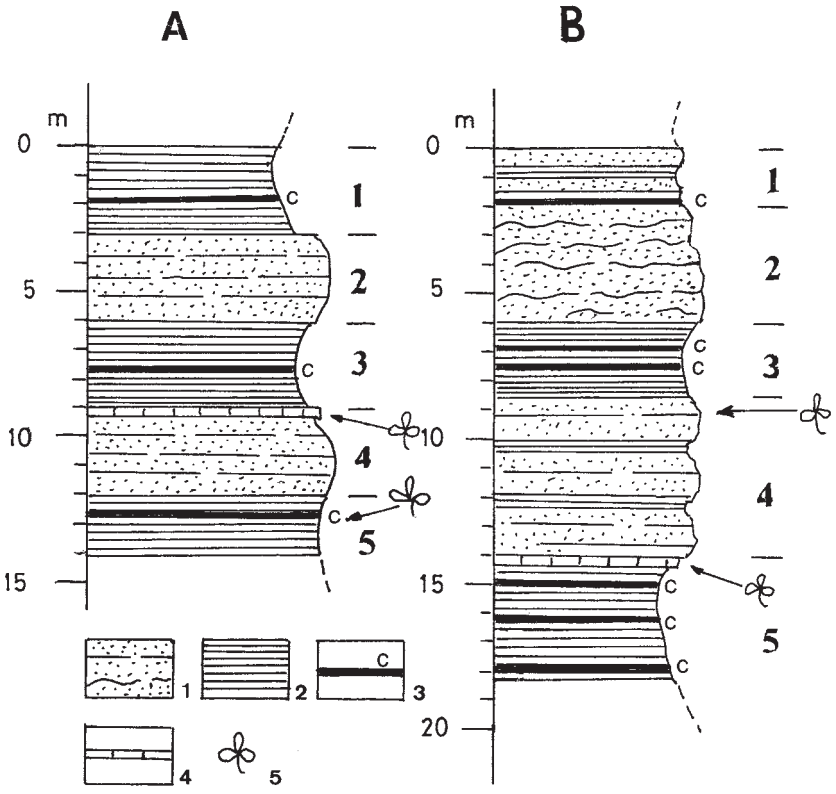

Fig. 4. Lithologic columns of Palaeogene strata (Skilvika Formation) at Calypsostranda, with position of macro oral remains. **A** – Rensdyrbekken, **B** – Tyvjobekken, **1** – sandstone, **2** – shale, coalshale, **3** – coal seam, **4** – siderite, **5** – macro ora remains

in diameter) and fragments (0.5–3 cm across, angular, sometimes rounded) of black stone coal (redeposited from Cretaceous strata ?) and plant detritus are frequent.

FOSSIL MATERIAL

Plant remains studied occurred in rocks of the Skilvika Formation, and originated from two sites: **14** in Tyvjobekken and **26** in Rensdyrbekken (Figs 3, 4). Specimens collected at the first location were sampled in layer 4 (sample no. 14/4), and assigned to successive catalogue numbers in the Palaeobotanical Museum of the Institute of Botany PAS (KRAM-P 245/7, 9, 17), and layer 5 (samples nos 14/4s), which were assigned to catalogue numbers KRAM-P 245/1–6, 8, 10–16, 18–45.

Samples collected at site 26 in Rensdyrbekken originated from layer 4 and were numbered 26/4 (specimens KRAM-P 246/1–19), and from layer 3, numbered 26/3 (specimens KRAM-P 246/20-23).

The plant remains are preserved as impressions of leaf fragments, stems and a single fruit, mostly in sandstone and partly in siderite (KRAM-P 245/7, 9, 17 and KRAM-P 246/20–23). Small fragments of carbonized tissue are visible on some of them, and particularly on the stem impressions of a coniferous plant, however, it was impossible to obtain preparations suitable for studies of the cuticle.

SYSTEMATIC PART

Class Sphenopsida

Order Equisetales

Family Equisetaceae

Genus ***Equisetum*** L.

M a t e r i a l. KRAM-P 246/11; impression of a stem fragment.

D e s c r i p t i o n. Aerial stem longitudinally ribbed, 5.8 mm broad, 7.0 cm preserved length. Nodal diaphragm clearly visible.

R e m a r k s. Fossil remains of *Equisetum*, preserved as aerial stem impressions, are known from the Palaeogene of Spitsbergen (Nathorst 1910, Schloemer-Jäger 1958, Schweitzer 1980,

Zastawniak 1981, Kvaček & Manum 1997) and many other locations of Arctic oras of that age (among others Heer 1869, 1878, Seward & Holttum 1924, Boulter & Kvaček 1989).

Class Coniferopsida

Order Coniferales

Family Taxodiaceae

Metasequoia occidentalis (Newberry) Chaney 1951

Fig. 5: 1, Fig. 7: 3a

1863 *Taxodium occidentale* Newberry, p. 516
1876 *Sequoia disticha* Heer, p. 63, Pl. 12, fig. 2a, Pl. 13, figs 9–11
1958 *Metasequoia occidentalis* (Newberry) Chaney; Schloemer-Jäger, p. 54, Pl. 8, figs 5, 6, Pl. 9, figs 1, 2, text-figs 10, 11.
1974 *Metasequoia occidentalis* (Newberry) Chaney; Schweitzer, p. 27, Pl. 4, figs 5, 6, Pl. 5, figs 1, 3–7, Pl. 7, figs 1–7, text-figs 9, 10, 13, 14
1981 *Metasequoia occidentalis* (Newberry) Chaney; Zastawniak, Pl. 1, figs 1, 2
1989 *Metasequoia occidentalis* (Newberry) Chaney; Boulter & Kvaček, p. 40, Pl. 6, figs 1–5

Material. KRAM-P 245/3, 7, 8, 12, 17/III, 246/1–4, 6–10, 12–19/1+2, 20; 23 specimens with numerous impressions of leafy branchlets.

Description. Impressions of dwarf shoots with needles attached oppositely and rather densely. Needles up to 3 mm wide and 15 mm long, short-petiolate; their bases converging at the stem axis, forming a characteristic pattern on its surface.

Remarks. The mostly stems and cones of *Metasequoia* that have so far been found in fossil oras, have been assigned to fossil species *M. occidentalis* (Newberry) Chaney. It occurred in the Palaeogene oras of the Arctic and North America; its distribution map is shown in a publication by Schloemer-Jäger (1958).

It is worth noticing that the genus was first described only on the basis of fossil remains (Miki 1941), before the extant trees of *Metasequoia glyptostroboides* were identified by Hu & Cheng (1948). These deciduous trees nowadays reach 45 m in height; they grow in Hubei, Hunan, and Sichuan provinces in China, in river valleys and wet habitats at altitudes of 800–1500 m (Ying et al. 1993).

Class Magnoliopsida

Order Hamamelidales

Family Platanaceae

Morpho-genus ***Platanites*** Forbes 1851

Fig. 6

Material. 245/13, 30/I, 33, 40, 42, 44/1, 246/5/I, II; 8 impressions of leaf fragments.

Description. Lea ets trilobate, between 10 and 20 cm broad, wider than long. Lobe apices and base of whole leaf unknown, leaf margin not preserved. Midveins of lateral lobes diverge from the primary vein of the central lobe at an angle of about 45°. Numerous secondary veins, placed alternately and clearly visible, branch off the primary vein of the central lobe and the midveins of the lateral lobes. Tertiaries perpendicular to secondaries, parallel to one another, sometimes forked between the lateral veins. Veins of higher orders form a distinct reticulum.

Remarks. The preserved leaf fragments show characteristic features of the venation of fossil Platanaceae leaves. Because of the absence of diagnostically important morphological features in the examined specimens (shape of whole leaves, shape of base and apex, character of leaf margin, and others), it is impossible to determine them to species.

Order Cercidiphyllales

Family Trochodendraceae vel Cercidiphyllaceae

Morpho-genus ***Trochodendroides*** Berry 1922

Fig. 5: 2–10

Material. 245/1, 5, 10, 11/II, 17/I, 20, 21, 22, 26/1+2, 27, 28, 30/II, 32, 34, 37, 41, 43/I, III, 246/12, 16; 20 impressions of leaf fragments.

Description. Whole leaves ovate or almost circular, up to 7 cm broad and long, leaf base deeply cordate, apex not preserved, leaf margins invisible. Venation actinodromous. Two arcuate primaries run on each side of the midvein. These and the lateral veins are connected in the central part of their course by perpendicular tertiaries, sometimes forked, and forming a reticulum of distinct loops at the

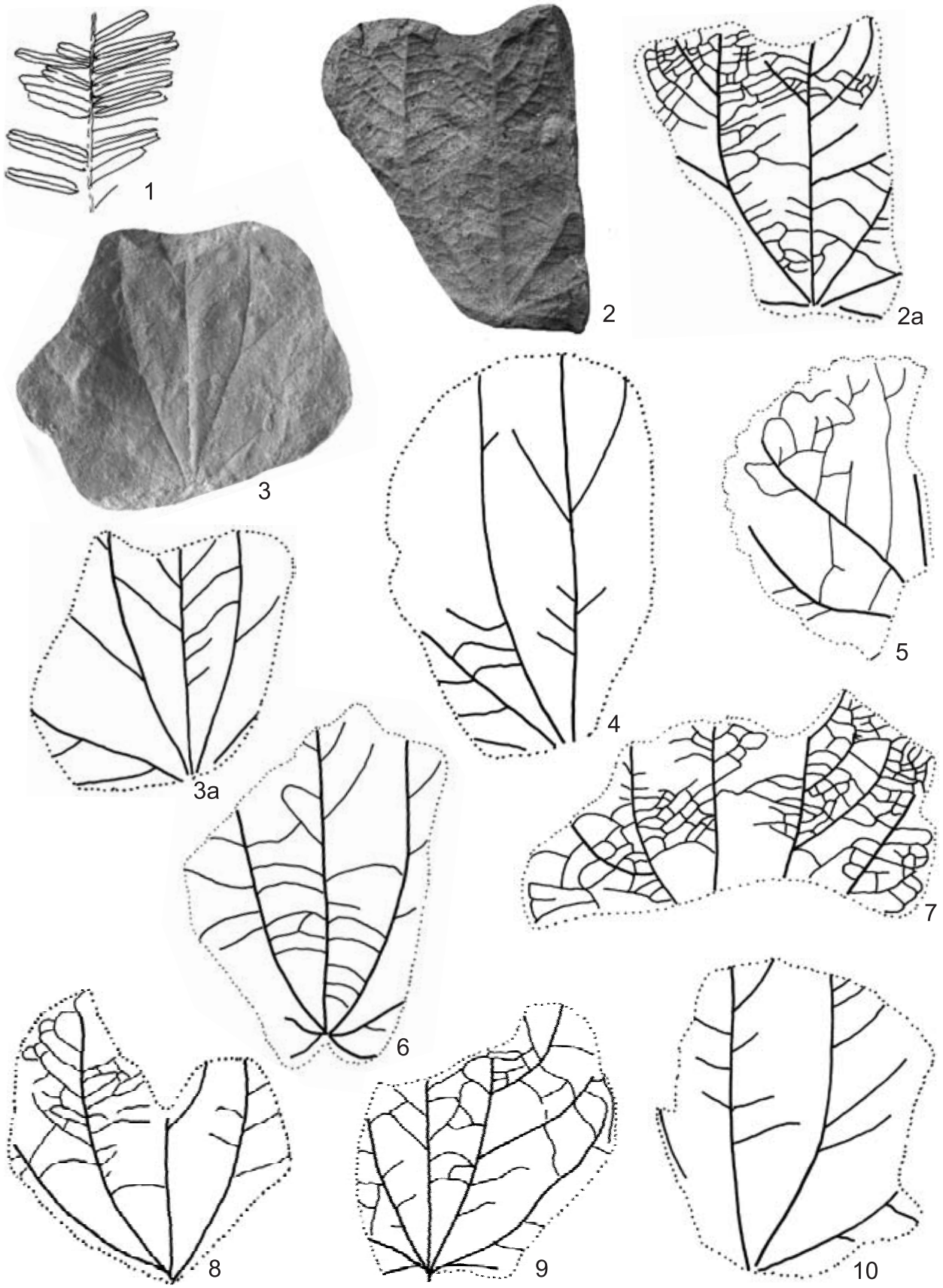

Fig. 5. **1** – *Metasequoia occidentalis* (Newberry) Chaney, specimen KRAM-P No. 245/8, Tyvjobekken; *Trochodendroides* Berry: **2**, **2a** – specimen KRAM-P No. 245/34, Tyvjobekken; **3**, **3a** – specimen KRAM-P No. 245/22, Rensdyrbekken; **4** – specimen KRAM-P No. 245/10, Tyvjobekken; **5** – specimen KRAM-P No. 245/17/I, Rensdyrbekken; **6** – specimen KRAM-P No. 245/5, Tyvjobekken; **7** – specimen KRAM-P No. 245/37, Tyvjobekken; **8** – specimen KRAM-P No. 245/28, Tyvjobekken; **9** – specimen KRAM-P No. 245/11/II, Tyvjobekken; **10** – specimen KRAM-P No. 245/21, Tyvjobekken (all specimens natural size). Photo K. Romeyko-Hurko

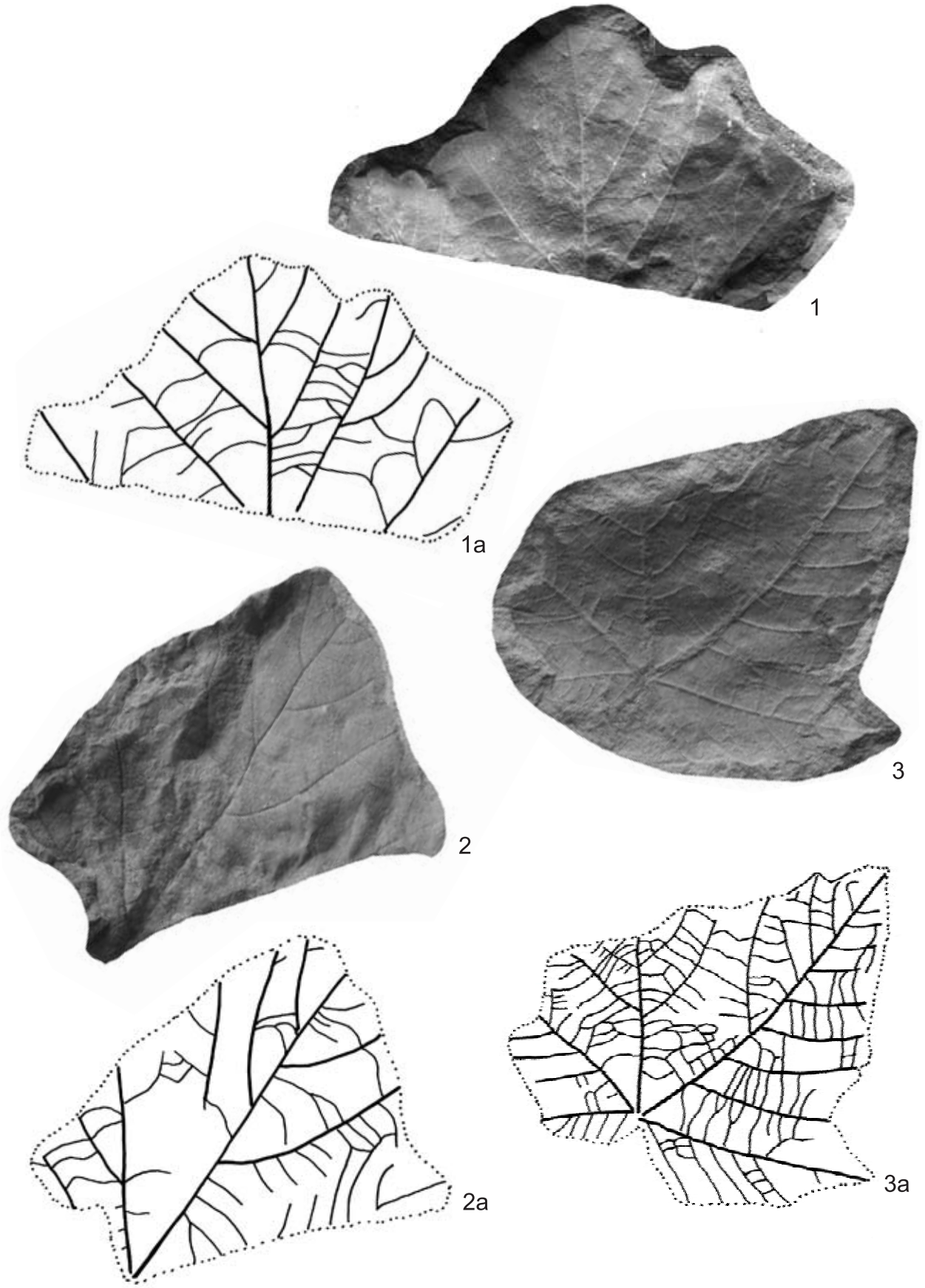

Fig. 6. *Platanites* Forbes (natural size): **1**, **1a** – specimen No. KRAM-P 246/5/II, Rensdyrbekken; **2**, **2a** – specimen KRAM-P No. 245/30/I, Tyvjobekken; **3**, **3a** – specimen KRAM-P No. 245/33 Tyvjobekken (all specimens natural size). Photo K. Romeyko-Hurko

leaf margins. Some specimens show a reticulum with tiny forked veinlets.

R e m a r k s. Leaves of this type, characteristic of the Arctic Palaeogene oras, have usually been described under the name of the contemporary genus *Cercidiphyllum* Sieb. & Zucc. According to Boulter and Kvaček (1989) the contemporary name should not be used for the remains of similar types of leaf representing undoubtedly extinct genera, and should be replaced by the name of the morpho-genus *Trochodendroides* Berry. The same authors discuss in detail its synonyms.

A leaf impression with similar venation, determined as *Trochodendroides arctica* (Heer) Berry, was found in the Palaeogene ora of Forlandsundet (Zastawniak 1981).

Determination of specimens from Bellsund to species is impossible because the leaf margins have not been preserved; it is their structure which constitutes an important diagnostic feature.

Plants with leaves of the *Trochodendroides* type, known from the Upper Cretaceous of Siberia and Japan and widely distributed in all Arctic Tertiary oras, died out during the Eocene and were replaced in the Oligocene by the deciduous trees of *Cercidiphyllum* Sieb. & Zucc., which survived in Europe until the Pliocene (Jähnichen et al. 1980).

Family Cercidiphyllaceae

Nyssidium arcticum (Heer) Iljinskaja 1974

Fig. 7

1869 *Nyssa arctica* Heer, p. 477, Pl. 43, fig. 12c, Pl. 50, fig. 6, 6b
1876 *Nyssa arctica* Heer; Heer, p. 80, Pl. 19, figs 1–10
1974 *Nyssidium arcticum* (Heer) Iljinskaja; Ili'nskaya, p. 124, Pl. 53, figs 9–13
1984 *Nyssidium arcticum* (Heer) Iljinskaja; Crane, p. 211, figs 18–25, 26A, B, 27–48, 49A,B, 50–53
1994 *Nyssidium arcticum* (Heer) Iljinskaja; Kvaček et al., p. 111, Pl. 3, figs 9–10.

M a t e r i a l. 245/17/II; 1 impression of a fruit.

D e s c r i p t i o n. Fruit 19 mm long and 10 mm broad, widest centrally, elliptical and steadily narrowing, partially damaged on one side. Numerous longitudinal surface bands are visible; they are most numerous and interconnected in the central part, so at the narrow

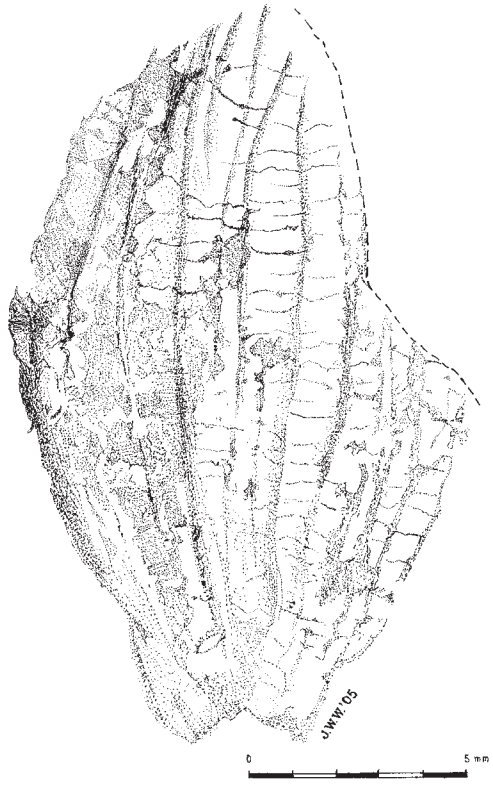

Fig. 7. *Nyssidium arcticum* (Heer) Iljinskaja, fruit, specimen KRAM-P No. 245/17/II, Rensdyrbekken. Drawing by J.W. Wieser

ends there are fewer of them. Between them there are numerous tiny, parallel, transverse striations. On the surface of the impression black carbonized matter is visible, it is probably the remnant of the fruit's external tissue (exocarp).

R e m a r k s. The discovered impression of a fruit fragment corresponds to the description of the species *Nyssa arctica* Heer from the Palaeogene of Western Greenland (Heer 1869), reported later on by Heer (1876) from Spitsbergen from the vicinity of Cap Lyell (i.e. the Calypsostranda area) where its remains were rather numerous, and from Scott-Gletscher (Scottbreen of the same area). Remains of this type were assigned by Il'inskaya (1974) to the artificial genus *Nyssidium* Heer because they had nothing in common with the extant genus *Nyssa* L., occurring in North America and Eastern Asia.

The fruits of *Nyssidium arcticum* (Heer) Iljinskaja are larger than in another species of the genus, *N. ekmanii* Heer.

Fossil fruits of *Nyssidium* Heer are known from many localities of the Upper Cretaceous (Krassilov 1973) and Palaeocene, among others from the Far East (Il'inskaya 1974) and

Great Britain where Crane (1984) found and described in detail whole *Nyssidium* infructescences and seeds of these plants.

Fruits of *Nyssidium* Heer often occur together with leaves of the fossil taxon *Trochodendroides* Berry (also known as *Cericidiphyllum* Sieb. & Zucc., which suggests that they could belong to the same plant (Brown 1939)). A detailed comparison of the remains of fossil *Nyssidium* Heer with the contemporary genus *Cercidiphyllum* Sieb. & Zucc. was undertaken by Crane (1984). However, the affinity of the contemporary plants to these fossil fruits has not yet been established (Kvaček et al. 1994).

?***Nyssidium ekmanii*** Heer 1870

1870 *Nyssidium ekmanii* Heer, p. 62, Pl. 15, figs 1–7.
1974 *Nyssidium ekmanii* Heer; Ili'nskaya, p. 123, Pl. 53, figs 14–17.
1994 *Nyssidium ekmanii* Heer; Kvaček et al., p. 111, Pl. 18, figs 2–3.

Material. KRAM-P No 245/17/II; 1 impression of a fruit fragment.

Description. Impression of a single fruit, narrowly elliptical, about 10 mm long and 5 mm broad at its widest point. Surface sculpture not visible.

Remarks. Determination is highly problematic because the specimen is in a poor state of preservation (longitudinal surface bands are invisible). In addition to the fruit impression, a leaf impression of *Trochodendroides* Berry can be seen.

Order Fagales

Family Betulaceae

Morpho-genus ***Corylites*** Gardner (1887) ex Seward & Holttum (1924)

Fig. 8: 1, 2, 3b, 4

Material. 245/3, 15, 26/3+4, 246/18, 22; 5 impressions of leaf fragments.

Description**.** Fragments of leaves up to 6 cm broad, their full length, shape and leaf margins unknown. Leaf base, visible in just one specimen, cordate. Venation pinnate. Lateral veins straight or slightly arcuate. The lowest pair of lateral veins diverge from the main vein at a higher angle than do the other secondaries. Fairly numerous regular straight branches diverge from the two lowest pairs of lateral veins towards the leaf margins.

Remarks. Venation of the lower parts of leaves is characteristic of the fossil taxon *Corylites hebridicus* Seward & Holttum. The specimens mentioned were, however, identified only to genus because it was impossible to determine other morphological features of the leaves.

Leaves of this type, rather common in the Arctic Palaeogene oras, have been described under different names, among others *Corylus macquarrii* (Forbes) Heer, *Corylites macquarrii* (Forbes) Gardner or *Alnites macquarrii* Forbes (Boulter & Kvaček 1989). An impression of a leaf fragment was described under the latter name from the Palaeogene deposits of Forlandsundet, western Spitsbergen (Zastawniak 1981). According to Boulter and Kvaček (op. cit.) catkins described as ?*Alnites* sp., found in the same ora (Zastawniak op. cit.), also belong to this fossil plant.

The synonyms of the fossil *Corylites hebridicus* Seward & Holttum and its geographical and geological distribution were widely discussed by Boulter and Kvaček (1989) in their publication about the Palaeocene ora of the Isle of Mull, in which its remains were quite numerous. These authors also examined the cuticle of the fossil leaves, and assigned them to the family Betulaceae.

Order ?Fagales

Family ?Fagaceae

Morpho-genus ?***Ushia*** Kolakovskij 1965

Fig. 8: 5

Material. KRAM-P 245/16; 1 impression of a leaf fragment.

Description. Fragment of leaf more than 7 cm long and 5 cm broad. Total length of the leaf and its shape are unknown. Preserved is a fragment of leaf margin in the upper part of the leaf, with one large triangular tooth and a rounded incision above it. Venation craspedodromous. Lateral veins with visible branchlets at the leaf margins and also in the lower part of the leaf. Tertiaries percurrent.

Remarks. The preserved leaf fragment suggests, the complete leaf would have been obovate, typical of the leaves of the morpho-genus

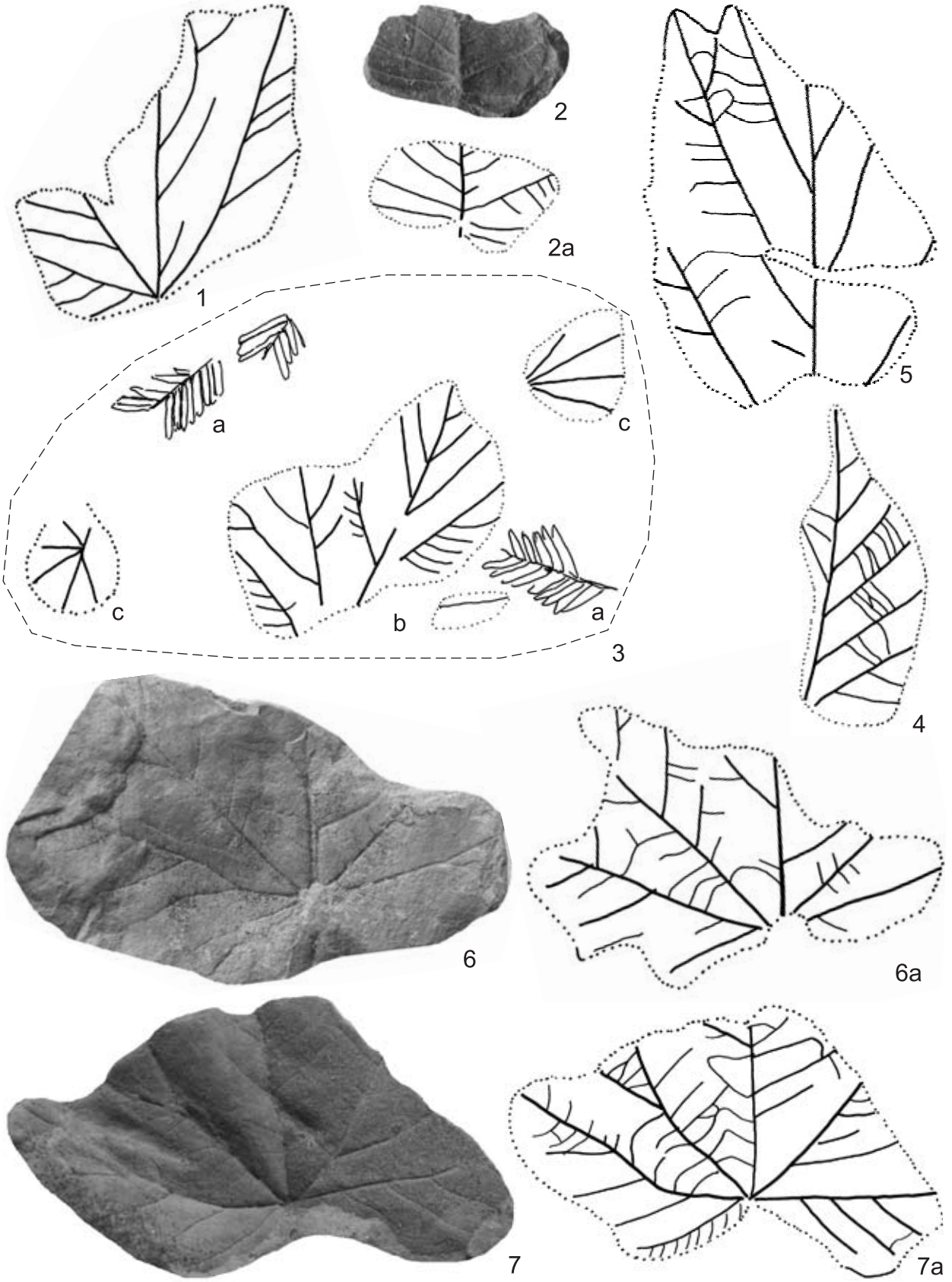

Fig. 8. *Corylites* Gardner ex Seward & Holttum (natural size): **1** – specimen KRAM-P No. 245/26/3+4;**2**, **2a** – 246/22, Rensdyrbekken; **3** – specimen KRAM-P No. 245/3: **a** – *Metasequoia occidentalis* (Newberry) Chaney, **b** – *Corylites* Gardner ex Seward & Holttum, **c** – Dicotyledones gen. et sp. div., Tyvjobekken; **4** – *Corylites* Gardner ex Seward & Holttum – specimen KRAM-P No. 245/15, Tyvjobekken, **5** – ? *Ushia* Kolakovskij, specimen KRAM-P No. 245/16, Tyvjobekken; **6**, **6a** – *Vitiphyllum* Nathorst: specimen KRAM-P No. 245/43/II, Tyvjobekken, **7**, **7a** – specimen KRAM-P No. 245/2, Tyvjobekken (all specimens natural size). Photo K.Romeyko-Hurko

Ushia Kolakovskij. Also characteristic of this genus are the shape and size of the marginal tooth, craspedodromous venation and branching of the lateral veins in the lower part of the leaf (Makulbekov 1982).

Order ?Rhamnales

Family ?Vitaceae

Morpho-genus ***Vitiphyllum*** Nathorst 1888

Fig. 8: 6, 7

Material. KRAM-P 245/2, 4, 11/I, 43/II; 4 impressions of leaf fragments.

Description. Leaves actinodromous, width slightly exceeding 8 cm. Leaf length and shape, shape of apex, as well as the nature of the leaf margins unknown. Base deeply cordate. From a single point at the base the medial primary vein and two lateral thin veins on each side of it emanate. From the lower pair of these veins numerous lateral veins branch off abmedially. Tertiaries, at intervals of about 3–4 mm, connect neighbouring veins, between them there is a distinct marked reticulum of veins of higher order.

Remarks. The pattern of leaf venation corresponds to that characteristic of the leaf remains of *Vitiphyllum sewardii* Boulter & Kvaček from the Palaeocene ora of the Isle of Mull (Boulter & Kvaček 1989). The species, according to its authors, belongs to the Vitaceae and represents the genus *Vitis*.

Order Sapindales

Family Hippocastanaceae

Aesculus longipedunculus
Schloemer-Jäger 1958

Fig. 9: 2

1958 *Aesculus longipedunculus* Schloemer-Jäger, p. 79, Pl. 12, figs 3–5, text-fig. 21a–d.

1994 *"Aesculus" longipedunculus* Schloemer-Jäger; Kvaček et al., p. 116, pl. 8, figs 1–10, pl. 17, fig. 12, pl. 19, figs 1, 5.

Material. 245/25/1+2; 1 impression of a leaflet fragment.

Description. Lea et 12 cm long and at least 5 cm broad, probably narrowly obovate. From the main vein lateral veins depart at irregular intervals. In the upper part of the lea et these are distinctly arcuate and interconnected by distinct loops. Tertiaries run obliquely to the lateral veins. Margin of the lea et is not preserved.

Remarks. Remains with similar venation, but with preserved leaf margins, were described by Schloemer-Jäger (1958) under the name of *Aesculus longipedunculus* (Hippocastanaceae) from the Palaeocene ora of Brøggerhalvøya, Spitsbergen. According to Kvaček et al. (1994) it is more likely that it belongs to the family Juglandaceae. However, Manchester (2001) described similar *Aesculus* foliage from Palaeogene of North America.

Family ?Sapindaceae

Subfamily ?Aceroideae

genus ***"Acer"*** L.

Fig. 9: 1, Fig. 10: 1–3

Material. KRAM-P 245/23, 24, 44/1; 3 impressions of leaf fragments.

Description. The preserved fragments of large leaves are up to 9 cm long and broad. The fragment of the largest leaf is probably its lower lobe, with a short section of the leaf margin preserved and a distinct tooth. Venation of two specimens actinodromous, but also two primary veins of lobes are preserved. Secondary veins are slightly arcuate; tertiary veins percurrent, simple or forked.

Remarks. Remains of leaves of this type were described from the Palaeogene of Spitsbergen by Schloemer-Jäger (1958) under the name *Acer spitzbergense* Schloemer-Jäger, who noted their unusual size (as much as 24 cm wide). They have a similar pattern of secondary and tertiary venation as the leaves of the examined ora. However, it is uncertain whether in this case the fossil remains do represent the genus *Acer* L.

Angiospermae incertae sedis

Dicotyledones gen. et sp. div.

Fig. 8: 3c, Fig. 9: 4–6

Material. 245/1, 4, 6, 14, 16, 18, 19, 23, 24, 29, 31, 35, 36, 38, 39/I, 44/3, 246/3, 6, 7, 12, 13, 17; 22 impressions of leaf fragments.

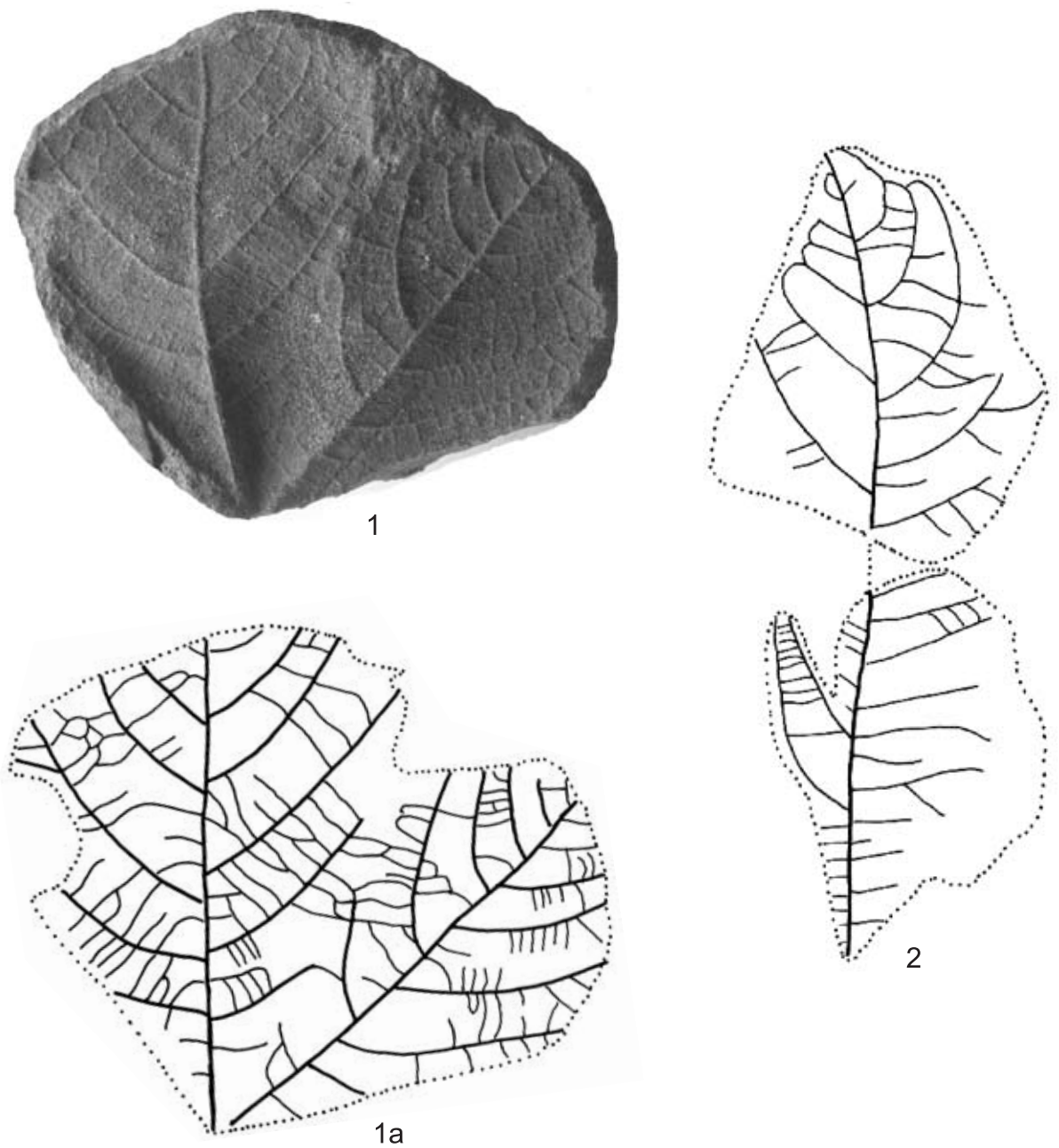

Fig. 9. "*Acer*" sp. (natural size): **1** – specimen KRAM-P No. 245/24, Tyvjobekken, **2** – specimen KRAM-P No. 245/44/1, Tyvjobekken, **3** – specimen KRAM-P No. 245/4; Dicotyledones gen. et sp. div.: **4** – specimen KRAM-P No. 245/14, Tyvjobekken, **5** – specimen KRAM-P No. 245/18, Tyvjobekken, **6** – specimen KRAM-P No. 246/7 Rensdyrbekken. Photo K.Romeyko-Hurko

D e s c r i p t i o n. The impressions are of small leaf fragments with differing venation (partly craspedodromous), from leaves of unknown shape and size. Some of them were relatively small leaves (245/18, 31) but most were large, a few could have belonged to one or more of the above-mentioned taxa. Worth noticing is a fragment of a petiolate leaf with five palmate veins (KRAM-P 245/14). Another specimen (KRAM-P 245/23) is a leaf fragment, at least trilobate and rather large, 13 cm broad or more, of which preserved were the main vein of the central lobe and a main vein of a lateral lobe, numerous lateral arcuate veins placed alternately at rather regular intervals and connected by tertiaries which are straight, simple or forked and interconnected. Yet another specimen (KRAM-P 245/24) is part of a larger leaf, whose form is difficult to ascertain. It was probably also lobate and a distinct tooth is visible at its margin. The marginal veins form well-defined loops, while third order venation is also very clear; these latter are most often interconnected forming a reticulum with the fourth order veins.

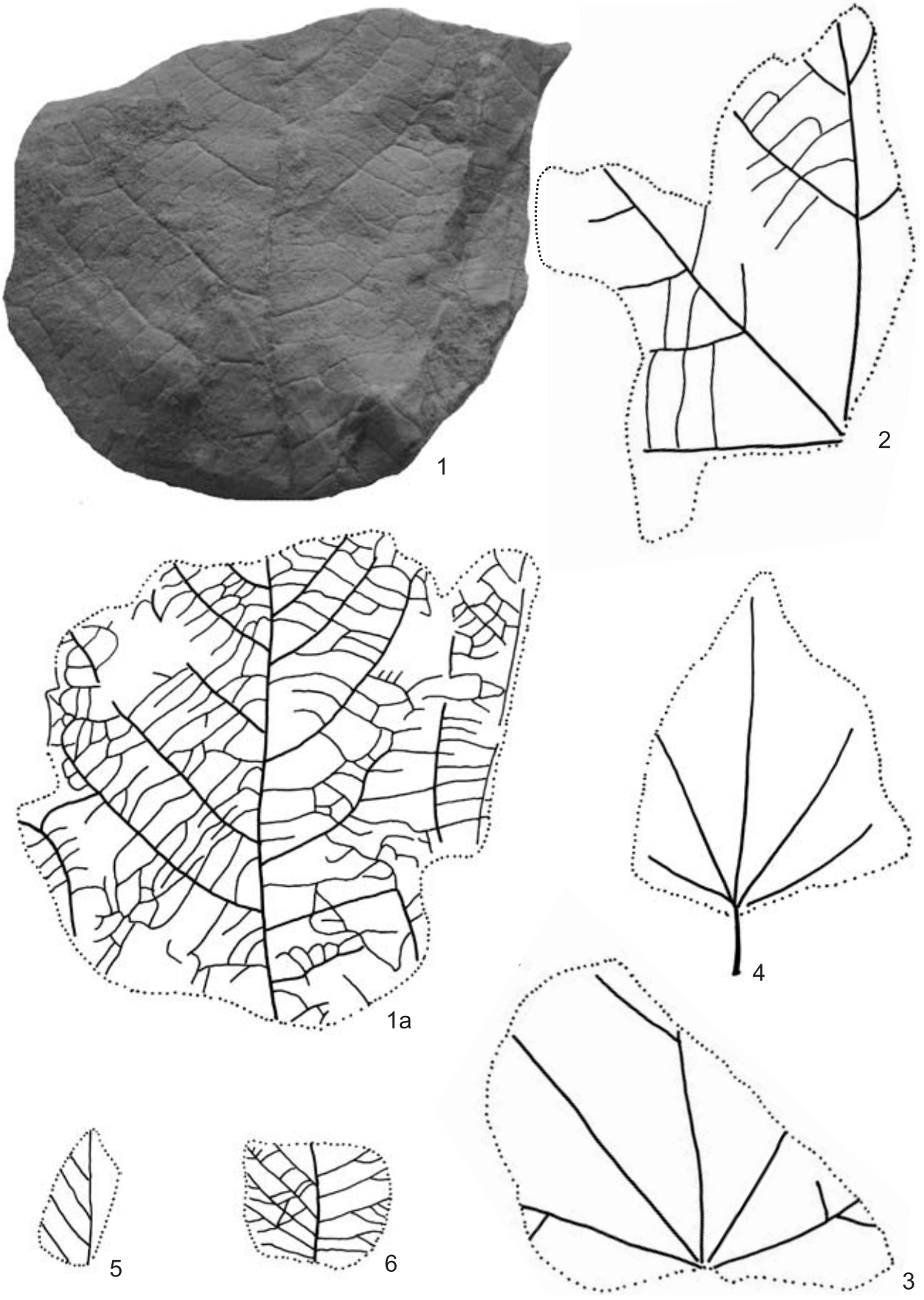

Fig. 10. **1**, **1a –** "*Acer*" sp.: specimen KRAM-P No. 245/23, Tyvjobekken; **2** – *Aesculus longipedunculus* Schloemer-Jäger, specimen KRAM-P No. 245/25/1+2, Tyvjobekken (all specimens natural size). Photo K.Romeyko-Hurko

Remarks. The preserved material is too incomplete to allow determination of any of the discovered fragments to a family or genus. One can say only that they belonged to many different plant genera.

Monocotyledones gen. et sp. indet.

Material. KRAM-P 245/9, 39/II, 246/21; 3 impressions of shoot or leaf fragments.

Description. Impressions of strap-like fragments on leaves of different widths (9 mm to 19 mm). The narrower specimens show a fairly distinct medial vein and numerous delicate veins of higher order running parallel to it on both sides.

Remarks. A more precise determination of the remains in this state of preservation has not been possible.

STRATIGRAPHIC AGE OF PREVIOUSLY INVESTIGATED PLANT REMAINS

Macro oral remains specifically previously determined from the Calypsostranda Group included Pteridophyta, Gymnospermae and Angiospermae (Livshits 1974, Schweitzer 1974, Lehmann et al. 1978, Thiedig et al. 1979). The spores and pollen from the Calypsostranda Group (Manum 1962, Thiedig et al. 1979) include Bryophyta (*Sphagnum* sp.), Pteridophyta (*Lycopodium* sp., *Selaginella* sp., *Osmunda* sp., *Lygodium* sp., *Aneimia* sp., *Gleichenia* sp. and Polypodiaceae), Gymnospermae (Cycadales, Caytoniales, Ginkgoales, moreover Coniferales: *Taxodium* sp. and *Sciadopitys* sp.) and Angiospermae (*Tilia* sp., *Castanea* sp., *Betula* sp., *Corylus* sp., *Myrica* sp., *Ulmus* sp., *Ericipites* sp. and *Viburnum* sp.).

This plant assemblage was considered by Livshits (1974) to be of Oligocene age. On the basis of dinocysts (Head 1984, Manum & Throndsen 1986), this age has been corrected to late Eocene-early Oligocene.

CONCLUSIONS

The list of fossil plant taxa, determined for particular strata and locations, are given in Table 1. Most of them are impressions of leaves and shoots, only two are fossil fruit impressions (*Nyssidium*). Angiosperm leaf remains

Table 1. Plant taxa from the Skilvika Formation (Calypsostranda Group, late Palaeogene) of Bellsund, Spitsbergen

Taxon	Tyvjobekken		Rensdyrbekken	
	Layer 4	Layer 5	Layer 4	Layer 5
Sphenophyta Equisetaceae *Equisetum* L.			1	
Coniferopsida Taxodiaceae *Metasequoia occidentalis* (Newberry) Chaney	2	3	17	1
Magnoliopsida Platanaceae *Platanites* Forbes		6	2	
Trochodendraceae-Cercidiphyllaceae *Trochodendroides* Berry	1	17	2	
Cercidiphyllaceae *Nyssidium arcticum* (Heer) Iljinskaja *Nyssidium ekmanii* Heer	1 fruit 1 fruit			
Betulaceae *Corylites* Gardner ex Seward & Holttum		3	2	
?Fagaceae *Ushia* Kolakovskij			1	
Hippocastanaceae *Aesculus longipedunculus* Schloemer-Jäger		1		
?Sapindaceae "*Acer*" sp.		3		
?Vitaceae *Vitiphyllum* Nathorst	4			
Angiospermae incertae sedis Dicotyledones gen. et sp. div.	1	16	6	
Liliopsida Monocotyledones gen. et sp. indet.		2	1	

have been preserved only as fragments; details of their base and apex shape and leaf margin are unknown (with a few exceptions). In view of this fact, they have been identified only to genus.

On the basis of an analysis of the taxonomic composition of the determined remains it was found that the fossil material from Bellsund is dominated by two genera: *Metasequoia* (Coniferae) and *Trochodendroides* – a morpho-genus of the Angiospermae, families Trochodendraceae-Cercidiphyllaceae. The site Tyvjobekken is undoubtedly richer in Angiospermae, while most of the *Metasequoia* specimens came from Rensdyrbekken; however, it seems obvious that these quantitative differences are not very significant.

Spitsbergen lies in the Tertiary Atlantic-boreal Bioprovince where Mai (1995) distinguished a few oristic complexes of different age. It is accepted (on the basis of an analysis of the discovered fossil plant remains) that the examined fossil ora corresponds to the late Eocene/Oligocene oristic complex of Brøggerhalvøya (Mai 1995, p. 342). In this complex, as in the older Palaeogene, the most important plant community is the so-called polar broad-leaved deciduous forest, as defined by Wolfe (1985). During the Palaeogene this forest, composed of coniferous and broad-leaves deciduous trees, and containing many different taxa of woody dicotyledonae, covered extensive upland areas in the Arctic up to about 70° N (Willis & McElwain 2002). According to Schweitzer (1974) the landscape of the Bellsund (Spitsbergen) region was dominated at that time by numerous lakes (Schweitzer 1974, 1980), whose shore regions consisted of low lying meadows with horsetail (*Equisetum*) and different monocotyledonous plants (Monocotyledones gen. et sp. indet.). The margins of swamps were overgrown by the forest of *Metasequoia* and *Trochodendroides*, while the higher ground was occupied by coniferous trees of the evergreen genera *Sequoia, Chamaecyparis* and *Taiwania* and the deciduous *Taxodium* or *Pseudolarix* (Mai 1995). Among trees of the Angiospermae there occurred *Aesculus longipedunculus, Corylites, Fagopsiphyllum, Juglandiphyllites, Platanites, Vitiphyllum, Acer* and others. According to Schweitzer (1980), the climate of the early Tertiary of Spitsbergen is best characterized by coniferous taxa from such genera as *Taxodium, Glyptostrobus, Sequoia* and *Sciadopitys*, in addition to *Metasequoia*; this conclusion has been reinforced by palynological analysis (Manum 1962). On the basis of the vegetation Schweitzer (op. cit.) determined the climate as temperate, warm, and similar to that which dominated the later Middle Miocene of Central Europe, allowing some monthly isotherms to dip below 0°C, at least in the lowlands.

Because of the poor state of preservation of the analyzed fossil material and an insufficient number of leaf specimens, it has been impossible to use the CLAMP method (Climate-Leaf Analysis Multivariate Program), introduced by Wolfe (1993), allowing one to determine the most important climatic parameters of the fossil ora on the basis of leaf physiognomy. One should notice, however, that the material analyzed in the present paper is characterized, like other fossil oras of Spitsbergen (among others Kvaček et al. 1994), by two particular features: "firstly, high variability within the dominant taxonomic groups, and secondly, the occurrence of 'giant' leaves in most of them" (Kvaček et al. 1994, p. 110), which may be reliable premises for the determination of climate. The presence of mixed deciduous forest at high geographical latitudes is ascribed to the higher than currently estimated temperatures in the circumpolar regions during the Palaeogene and the specific light conditions, that is a deficit of daylight in winter and an excess of it in summer. Such climatic conditions must have been, according to Axelrod (1966), of primary importance for trees during the whole growing season. The above-mentioned 'giant' leaves of some plant taxa may have been their adaptation to the so-called long photosynthetic period, characterized by the narrow spectrum of solar radiation in summer, long days and relatively high temperatures (Wolfe 1985, Willis & McElwain 2002).

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