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MID-LATITUDE PALAEOGENE FLORAS OF EURASIA BOUND TO VOLCANIC SETTINGS AND PALAEOCLIMATIC EVENTS – EXPERIENCE OBTAINED FROM THE FAR EAST OF RUSSIA (SIKHOTE-ALIN') AND CENTRAL EUROPE (BOHEMIAN MASSIF)

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Abstract. A synthetic palaeofloristic study of the Palaeogene plant assemblages of two regions of mid-latitude Eurasia – Sikhote-Alin' (Russia) and Bohemian Massif (Central Europe) brings into focus the influence of volcanic activity and various taphonomical settings on the composition, diversity and relative frequencies of plant elements. The potential importance for the reconstruction of vegetation, environment and palaeoclimatic events during the Palaeogene is discussed on the basis of studies of two distant and floristically diverse parts of Eurasia.

■ Flora and vegetation, Palaeogene, volcanic setting, climatic events, palaeoecology, Eurasia

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Introduction

The fossil plant record has often been employed for tracing palaeoenvironmental and palaeoclimatic changes in the history of the Earth (Uhl et al. 2007). The accuracy of such estimates depends on exact analyses of plant assemblages in terms of taxonomy, ecology and environmental influence. The last empiric studies of Neogene floras of Europe (Kovar-Eder and Kvaček 2007, Kovar-Eder et al. 2008) arrived to a conclusion that the best indicators of palaeoclimatic conditions are those elements of a fossil plant assemblage that are considered to be mesophytic, e.g. not influenced by local substrate conditions, namely ground moisture. They represent the part of the ancient vegetation which was in equilibrium with the macroclimate. To produce more precise reconstructions of trends in climate during the Palaeogene in the Northern Hemisphere, we decided to survey those floras that are bound to volcanic settings and in the prevailing part reflect mesophytic vegetation. As there is some hesitation with the understanding of major palaeoclimatic events and their causes (Sijp and England 2004), two distant regions have been chosen and explored for this purpose. Our study relies on our personal experince with exploration of the Palaeogene of the Far East (first author) and Central Europe (two remaining authors), where our research activities have spanned several decades.

Concept of "volcanic floras" and taphonomical processes

(M. Akhmetiev and H. Walther)

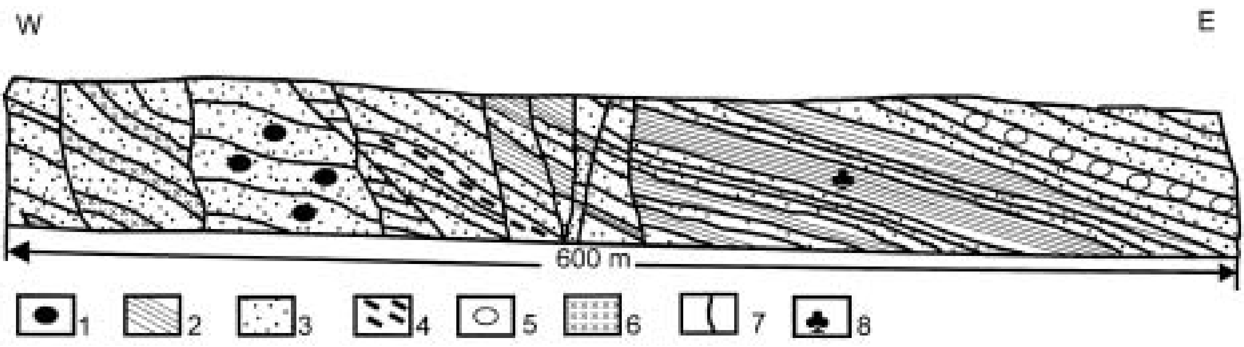
Studies of fossil plant assemblages, which are preserved in sub-aerial volcanic complexes, are much more complicated than those of sites connected with coal-bearing sedimentary basins, where plant fossils are concentrated in fluvial-lacustrine deposits and reflect as rule intrazonal riparian or near-shore vegetation. The coal basin assemblages are characterized by more or less stable uniform floristic composition and in many cases preserve stages of the vegetation succession that took place within homogenous plant formations of similar composition. Optimal preservation of carbonized compressions usually allows application of leaf epidermal studies, which is not always the case in studies of plant fossils preserved in volcanogenic fossiliferous layers. On the other hand, plant-bearing horizons in volcanic settings are limited in their extent both horizontally and laterally due to the facial diversity of volcanogenic rocks. An example of such depositional settings could be a section near the Nakatova Bay (North Sikhote-Alin' – Text-fig. 1). Plant-bearing sites also arose in different altitudes starting with sea level up to several hundred meter high levels.

There are several general differences between plant assemblages of volcanic areas and large sedimentary coal basins. We can mention at least some of characteristic features of the sites bound to volcanic settings.

1) Large diversity of conifers, which may dominate over specific sites, often reflected only in pollen records. Particularly, this is the case in the Eastern Sikhote-Alin' volcanic belt, as detailed below. Conifers are less diversified only where evergreen broad-leaved elements prevailed.
2) Considerable representation of shrubs and at the same time, an almost entire lack, or low diversity, of aquatic plants, which may occasionally occur in oxbow lakes or deposits of crater or caldera lakes.
3) High taxonomic diversity at the rank of families or genera usually represented by one or two species only.
4) Preservation of elements or plant groups, which are typical of zonal vegetation.
5) A high differentiation of ecological niches. This phenomenon may make reconstruction of coeval palaeofloristic levels, even within the same volcanic complex, highly difficult.
6) Individual aspects and differentiation of assemblages similar in age due to a wide range of landscape and facial conditions, under which the plant-bearing deposits arose, and also due to various influences of volcanic activity itself, or depositional processes.
7) Better possibilities for dating using radiometric methodologies (K-Ar, Ar-Ar of zircon, fission track), when the preservation of rocks is suitable and particularly when limited or no weathering processes took place.
8) Manifold mixture of sites including autochthonous (e.g., buried on the spot by volcanic ashes), par-autochthonous as well as allochthonous facially diversified assemblages.
9) Pioneer associations that formed part of the successions that arose during and after volcanic explosions and which destroyed the previous plant cover.
10) A noteworthy small size of leaves in specific cases of assemblages or sites, probably due to edaphic influence.
11) A high degree of endemism.
12) A higher representation of short-range taxa that survived only for a limited time span on the site.
13) Equivocal interpretation of palaeoclimatic conditions, particularly when considering autecology of conifers and evergreen angiosperms mixed together from various habitats in one assemblage.
14) Short stable periods that would allow vegetation to reach to a climax and high dynamics of a sedimentary environment between depositional centres differing in their extent.

Deposits of lakes and oxbow lake-swamp, which may concentrate within the volcanic landscape, are of two types. The first type includes lake deposits that arose far from the active volcanoes and mostly reflect a terrigenous environment. In such basins, volcanic products were represented by rare lava flows, terrigenous volcanic deposits, reworked pyroclastics or more frequently ash tuffites including decomposed volcanic glass. Such layers may attain a thickness of several tens of cm or more, depending on the distance from the active volcanoes. The second type of lake deposits within the volcanogenic setting are more intimately connected with volcanic products. Lake deposits of this type may extend over several tens of square km. They are usually connected with the volcano-tectonic trough systems. The thickness of such volcano-clastic rocks may attain over 100 m. They arose over much longer periods, often lasting over one million years. Such systems also include lakes of smaller size, ca. 1–2 square km. The thickness of fossiliferous strata is usually less than 10 m (Text-fig. 1).

Sometimes the lakes in a volcanic environment were so stable that diatomites, bituminous shales and similar deposits could accumulate there. Such examples can be found in East Asia, in the Miocene of the rivers Mul'pa and Botchi. The landscape of such reservoirs was connected with active volcanism, where lava flows dammed rivers or streams, which produced deposits of greater thickness. Such flooded zones formed more or less deep lakes and swamps, divided by uplands of fundament. Later on, such systems were buried by products of new volcanic phases. Most of the lacustrine deposits of this sort are rich in well preserved plant fossils, as a rule orientated parallel with the bedding as well as concentrations of algae, in particular diatoms. In many cases, the fossils are associated with deposits of standing water and swampy lakes. The sediments



Text-fig. 1. Geological section of the south-western coast in the Nakatova Bay, 28 km south of De Kastri village showing interbedding plant-bearing clays with tuffaceus argillites. 1 – tuff; 2 – tuffaceous argillate; 3 – sandy tuffite; 4 – interbed with lignitic fragments in bedded andesite; 5 – tuffitic conglomerate; 6 – basaltoid agglomerate; 7 – unconformity; 8 – plant-bearing level.

usually show graded bedding. Sandstones are mostly cemented by clay-quartzose and opal or zeolite matter. Such psammites may imitate and can be easily mistaken for acidic tuffs. The lava flows that penetrated into the basin deposits may have disturbed regular bedding and formed pillow lava accumulations.

Smaller water reservoirs of standing water arose by the damming of smaller streams. Such lakes lasted a shorter time, having been quickly filled by clay or destroyed by new lava flows that filled them. In such lakes, the sorting of sediments is lacking. Characteristic features are horizontal bedding, admixture of plant detritus or fragments of basalts and varied facial differentiation – lignite, stream and swamp deposits. Deposition of standing swamps was usually in the final stages of the sedimentary succession, in cases of longer gaps in volcanic activity.

A special type of fossiliferous deposits is a fill of maar or crater lakes. Such sites consist of deep fine-bedded bituminous clays and may contain exquisitely preserved plant as well as animal fossils (e.g. Messel in Germany). Their existence proceeded several hundred thousand years and they may attain many hundred meters in thickness. They may contain concentrations of algae (e.g. *Tetrahedron*). The maar usually started with a short-time explosive phase that formed the crater and the peripheral ring of pyroclastics, succeeded by the depositional filling phase. Fossils are widely scattered, not densely accumulated, preserved as autochthonous remains brought into the maar lake mostly by wind, sometimes as whole twigs and flowers or other light reproductive organs (winged fruits and seeds, branched inflorescences).

A special type of fossiliferous site is also the "petrified forest". Such sites arose within a volcanic landscape by sudden burial of trees by falling ash. The preservation of trunks took place subsequently by various mineralization processes which replaced wood tissue with mineral solutions of various kinds (calcareous, siliceous etc.). Such deposits are poorly or not bedded and seldom contain other plant organs besides wood.

Expositions of slopes influence the composition of plant assemblages, which usually include a richer spectrum of local flora. Coal seams are quite rare in volcanic localities. If they are present, then the seams are considerably thinner than in regions without volcanic influences. The coal seams in volcanic localities obviously arose in different ways – e.g. monocot mires buried under lava flows. Even in these sites a more or less extensive belt of riparian forests around lakes was developed. Important elements of such forests, influenced by ground water, are representatives of *Taxodium*, *Nyssa*, *Alnus*, *Liquidambar*, *Ulmus*, *Craigia* or *Cercidiphyllum.* The common zonal forest type in the Oligocene corresponds usually to the Mixed Mesophytic Forest comparable to extant forests in Eastern Asia and more rarely with the Mixed Forest in the mountain region of Central America. The Oligocene Mixed Mesophytic Forest in Central Europe contains new elements of invasion floras which immigrated during the transition between late Eocene to early Oligocene in different waves during the Oligocene to Oligocene/Miocene from Central Russia, western Siberia and the Far East after the closing of the Uralian seaway to Central Europe. These "modern" arctotertiary taxa sensu Kvaček (1994), e.g. representatives of *Acer*, *Betula*, *Carpinus*, *Cyclocarya*, *Fagus*, *Quercus* etc. can be very common under more temperate and warmer condition, while the invasion of new evergreen elements took place only rarely and depended on conditions changing towards warm-temperate to subtropical. Examples for these scientific interpretations are floras of the Late Oligocene, e.g. Kleinsaubernitz (Germany). These volcanic floras illustrate the mesophytic climax vegetation at a time more than 30 million years ago in Central Europe. The existence of relationships with the contemporary floras close to the Tertiary North Sea (the so-called lowland floras) is corroborated by the occurrence of the same accessory plant elements in both realms (for example Kvaček and Walther 2001, Walther and Kvaček 2007).

Preservation of plant fossils in volcanic environment

(H. Walther)

Volcanic activities during the history of land plant evolution have preserved mires or swamps, which included isolated plant remains as well as whole forest stands by permineralisation. Known worldwide is for example the Early Devonian locality of Rhynie with petrified mire overfilled with some of the first land plants and animals. Another example is the famous "Versteinerter Wald" in the Lower Permian petrified forests of Chemnitz in Saxony and elsewhere. In the Palaeogene, mainly during the Eocene and Oligocene of Central Europe, numerous important floras were also affected both directly and indirectly by volcanic events. Neovolcanic activities in the late Palaeogene of Central Europe were responsible for preservation of important and worldwide known plant bearing localities, mostly representing deposits of maar lakes, lake sides, volcanic uplands and slopes, calderas and other depressions. These include floras which are preserved under the specific conditions of a volcanic environment and are mostly composed of typical elements of zonal vegetation. The preservation of the plant cover is connected with optimal taphonomic conditions in diatomites (tripoli), bituminous shale deposits or laminated volcanic tuffs and tuffites. The bituminous content is suitable for preservation of mummified leaf fossils. Typical sites in Europe are widely distributed in all volcanic regions, from which we concentrated on the mountains of Doupov, České středohoří as well as Lusatia (Czech Republic, Germany).

Plant fossils are preserved in volcanoclastic sediments such as basaltic tuffs of differing granularity, from finely granular to coarsely granular and from laminated tuffs to non-bedded tuffs. In tuffites, a mixture of pyroclastic and detrital components, also including plant megafossil impressions exist. In some volcanic localities, such as Seifhennersdorf (Germany), plant remains are excellently preserved in claystone or mudstone, as impressions and also mummified samples. Important for the preservation of plants and animals in Central Europe were the bioliths such as diatomite or tripoli (freshwater diatoms) and oil shales containing masses of unicellular green algae such as *Tetrahedron* and *Botriococcus* (e.g. at Messel near Frankfurt/M., Germany – see Goth 1990, Schiller 2007). In many volcanic floras of

Central Europe as in the NE part of the Czech Republic and SE Germany (e.g. České středohoří and Lusatia Mts.) and also Hesse and Rhineland, the macrofloras are conserved in diatomites or bitumenous shales of differing quality. In some localities, for example Seifhennersdorf, Kundratice and the maar site of Kleinsaubernitz (Germany), leaf megafossils are mostly compressions, which often allow successful cuticle analysis (Kvaček and Walther 1998, Mai 1963, Walther 1964, Walther 1999, Walther and Kvaček 2007). The microslides demonstrate the high quality of the epidermis structure obtained which thus allows an impressive documentation by light microscope and SEM (e.g. Walther and Kvaček 2007, 2008). The assumed reason for this kind of preservation was reduced pressure from the overlying basaltic rocks of the tripoli seams and by different tuff beds between the diatomite seams. On the other hand, we have found other volcanic localities where plant remains were more or less completely covered by frustules of diatoms, which are completely inprinted into the leaf compressions. These traces can be sometimes so intensive, that all attempts for preparing the cuticle were unsuccessful. For example we have found these conditions in some localities in the České středohoří and Lusatia Mts. – e.g. Suletice, Suletice-Berand, Bechlejovice (Kvaček and Walther 1995, 1998). A specific form of preservation has been found in unbedded tuffs from the maar lake deposits at Hammerunterwiesenthal, the Erzgebirge Mts., Germany. For example, plant remains of scleromorphic leaves of an extinct *Ilex* species were three-dimensionally preserved with all details of gross-morphology (so called "pudding effect", after personal discussions with prof. David Ferguson, Vienna) (Walther and Kvaček 2008). In finely laminated tuffs, the leaf impressions, rarely also other compressions from the same locality, demonstrate good preservation of venation details. Impressions of leaves in more coarse-grained tuffs often have the leaf margin region only fragmentarily preserved, while the venation of the lamina can be completely preserved up to the tertiary vein category. Sometimes even the areoles are visible.

Going back to the tripoli (diatomites), another type of preservation can be found of leaf fragments in finely laminated diatomite. These paper-like coally layers of heavily bituminous shale were on various occasions covered by fragments of fern fronds of *Osmunda lignitum* and *Pronephrium stiriacum* (see Walther 1967, Walther and Kvaček 2007). These sediments are typical sapropelits that originated in the fomer lake floor under anaerobic conditions. Fossil fragments of animals are important in the plant bearing tripoli. Together with various fossils of insects and lower vertebrates (e.g. fish, reptiles) it is possible to obtain information with almost complete certainty regarding a particular position of the site relative to the fossil lake shore together with flora and fauna (Ahrens 1957, Böhme 2007, Prokop and Fikáček 2007, Walther and Kvaček 2007). It is also important to know the profile of the drilling or mines. In the case of the famous locality Seifhennersdorf, the sections of the research mining shaft drilled between 1951 to 1954 and the core (for its section see Walther and Kvaček 2007) have produced important data about the time of sedimentation in the freshwater lake and the accompanying volcanic activities (Ahrens 1957, Walther 1996, Walther and Kvaček 2007). Analogous information was also obtained for the complete profil of a research drilling from the late Oligocene maar locality in Kleinsaubernitz near Bautzen (Germany) (e.g. Suhr and Goth 1999, 2008, Walther 1999, Walther and Kvaček 2007).

Cenozoic floras of the Eastern Sikhote-Alin' Volcanic Belt

(M. Akhmetiev)

The eastern slope of the Sikhote-Alin' mountain range facing the Japan Sea and the Tatar Strait is a large volcanogenic complex composed of units ranging in age from the latest Cretaceous to the mid Cenozoic. It is included in the so-called Eastern Sikhote-Alin' Volcanic Belt, which extends meridionally over 1000 km. Its composition is heterogeneous, encompassing not less than five complexes of various ages, divided by brakes and gaps in volcanic activity. The most obvious regional hiatuses took place between the Senonian/Danian volcanoes of andesite–rhyolite groups and between the Eocene/Oligocene and Neogene basaltoid bodies. The mixture of more ancient and younger volcanic masses in the Northern and Central Sikhote-Alin' is expressed geographically more than in the stratigraphical sequence (Text-fig. 2). At mid-Palaeogene, a separate Andesite – basaltoid Belt arose below the eastern boundary of the continent. It covered an older Late Cretaceous – Early Palaeogene volcanic belt, but it did not expand southwards more than to the 46° latitude (Text-figs. 2, 3). Late Cenozoic basaltoid sheets and lava flows divide the belt into several areas with an independent local stratigraphy, but some units are close in age. The maps also show the main plant-bearing localities. The last stage of volcanic activity is represented by extrusive necks of dolerite cones (Text-fig. 4).

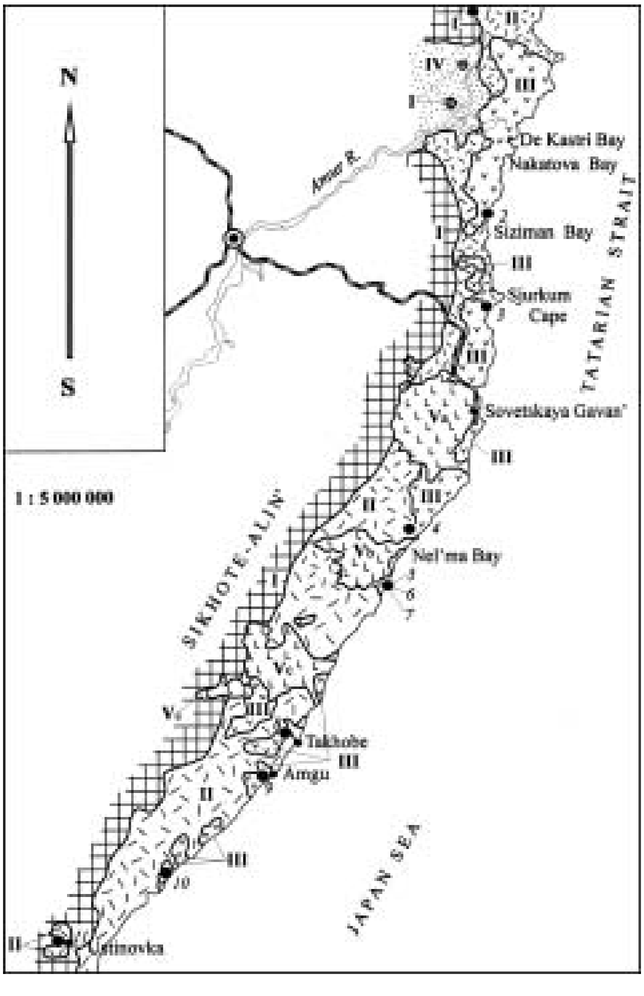
Danian floras of the Eastern Sikhote-Alin' Volcanic Belt

The Senonian – Danian volcanic complex is mostly represented by accumulated parts of volcanic masses and was eroded away in its upper part before the Eocene, when a kaolinite erosion crust arose. Most of the volcanic rocks of the so-called "Central Type" are connected there with the volcano-tectonic deep structures that are limited by various dislocations. The deposition of plant-bearing horizons and lenses occurred for only a limited time on the periphery of volcanic centres, where silt clay lacustrine deposits interfinger with fine-grained tuffs containing fragments of devitrificated volcanic glass or were overlain by more coarsely grained pyroclastics. Pyroclastic products may laterally pass into magmatic granitoids of the same age. In such cases, the correlation with a specific volcanic phase is usually equivocal. The western boundary of the Senonian/Danian belt is arbitrarily taken between the volcanic areas and the exposures of the Mesozoic basement. The eastern boundary is covered by waters of the Japan Sea and Tatar Strait (see Text-fig. 2).

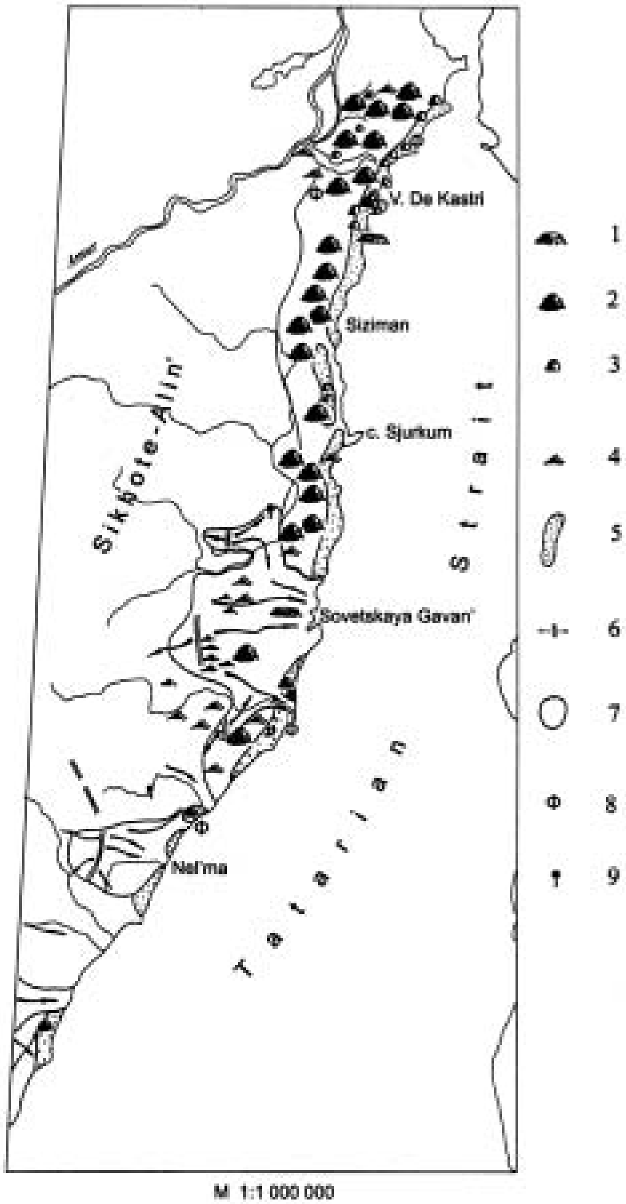
The floras described in detail below belong only to the upper part of the Senonian/Danian volcanic series, in particular belonging to the Danian. In contrast to Senonian volcanism, which produced mostly lava flows and pyroclastics of the andesitic–dacitic type, the volcanoes of the "Central Type" produced lavas of the rhyolitic type in the closing phases. At different distances from the volcanic centres, the volcanic products mixed with terrigenous lake deposits, or the full thickness of rocks consists of terrigenous deposits. Such volcano-detritic products belong to the Bogopol' and Tadushi Formations on the southern part of the belt, to the Takhobe Formation in the central part and to the Malo-Mikhaylovka Formation on the north. Among effusive and pyroclastic rocks, felsits, liparits and ingimbrites with sphaerolitic texture prevail. Further away from the volcanic centres, the rocks interfinger with variously grained ash tuffs, mixed with river and lacustrine deposits to a limited extent.

Malo-Mikhaylovka

On the northern boundary of the Sikhote-Alin' Volcanic Belt nearby the Amur River (Text-fig. 2) the Malo-Mikhaylovka Formation developed, where acidic magmatic types play an important role. The flora occurs in several elongate lenses of tuffitic-clastic deposits ca. 25 m thick. The exposures crop out at the base of the terrace of the Amur River between the villages of Malo-Mikhaylovka and Pad and from part of the central part of the NE syncline in both wings, inclined at 10–12° (Text-figs. 5–7). The fossiliferous deposits are partly tuffite, partly sandy clay and lignite in the basement with various effusive rocks. The corresponding andesites dated by K-Ar radiometric method as 74 Ma, are in the north and rhyolitic tuffs and lava flows in the



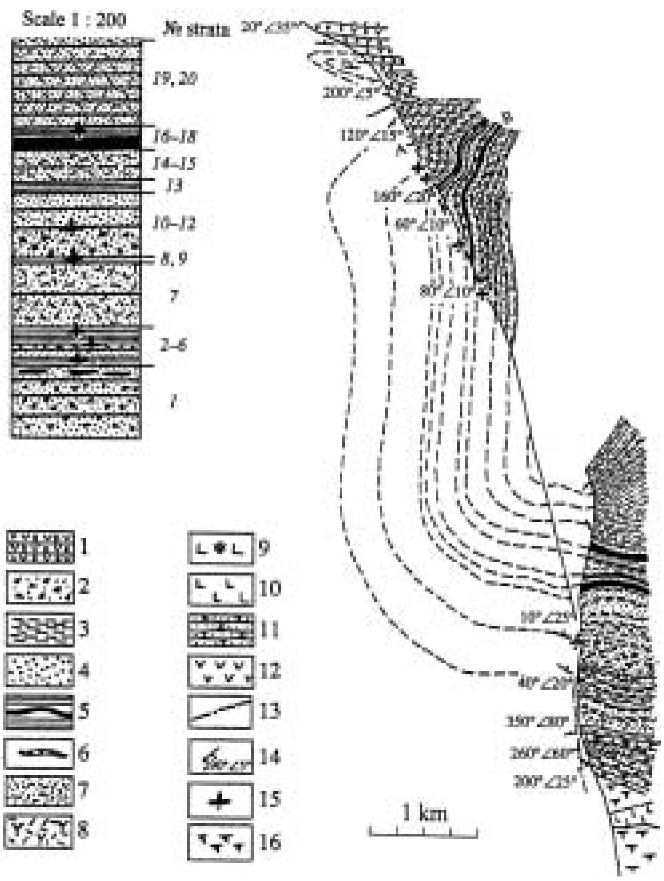
Text-fig. 2. Main geological structures of the eastern slope of the Sikhote-Alin' ridge and main plant-bearing localities of the Cenozoic floras.
I – Mesozoic folded basement; II – East Sikhote-Alin' Volcanic Belt (Late Cretaceous–Early Palaeocene); III – Near-Shore Basaltic Volcanic Belt (Eocene–Early Miocene); IV – Udyl Basin (Cenozoic); V – Late Neogene to Quaternary plateau-basalts; Va – Sovgavan plateau; Vb – Samarga plateau; Vc – Bikin plateau.
1 – Malo-Mikhaylovka; 2 – Siziman; 3 – Sjurkum; 4 – Botchi; 5 – Dembi; 6 – Bui; 7 – Sonje; 8 – Takhobe; 9 – Amgu; 10 – Velikaya Kema; 11 – Zerkal'naya (former Tadushi).



Text-fig. 3. Distribution of main types of volcanoes in the Near-Shore Volcanic Belt of Eastern Sikhote-Alin' (Eocene–Neogene).
1 – Central volcanoes (partly preserved); 2 – Central volcanoes (destructed); 3 – Shield and gentle sloping volcanoes with a dolerite or trachy-basaltic neck on the top; 4 – Lava and scoria cones; 5 – Pyroclastic, tuffaceous coarse- and fine-grained terrigenous sedimentary rocks, partly with plant-bearing levels; 6 – Eruption centers of plateau-basalts and the direction of lava flows; 7 – Main Late Cenozoic basaltic plateaus; 8 – Fumarol fields; 9 – Hot springs.

Text-fig. 4. A typical Oligocene–Early Miocene gentle-sloping Central volcano with an eruptive dolerite neck near the top – Nevelskoy "Cap".

Text-fig. 5. Malo-Mikhaylovka village. The view on outcrops of the Malo-Mikhaylovka plant-bearing sedimentary strata.



Text-fig. 6. Geological plan of Malo-Mikhaylovka. 1 – andesito-dacite; 2 – coarse-grained tuff; 3 – argillitic tuffite; 4 – tuffitic sandstone; 5 – lignite, coal clay; 6 – lenses of tuffitic conglomerate; 7 – acidic tuff; 8 – dacite; 9 – andesito-basalt; 10 – basalt; 11 – sandstone; 12 – andesite; 13 – break; 14 – inclination/direction of beds; 15 – plant-bearing levels; 16 – talus.

south. At an abandoned settlement, Pad, fine-grained plant-bearing rocks of these beds are replaced by rhyolitic tuffs. The same changes occur upwards in the section and demonstrate reduction of clastic deposits, influenced by volcanites.

The section was described in detail by Akhmetiev et al. (1976) who also collected plant remains there. Numerous lignite seamlets and accompanying lenses in the overlying and underlying deposits contain plant assemblages typical of swampy habitats that arose in an intermountain lacustrine basin extending over several square km. The basin is surrounded by volcanoes of the "Central Type", from which pyroclastic and terrigenous clastic material concentrated. In most types of rocks, particles of ash and volcanic glass are admixed. The hydrological regime changed periodically, lignite and lignitic clay with plant remains originated in a swampy environment and cross-bedded sand and pebble deposits arose during river floods (Text-fig. 7).

In the black lignitic tuffite/claystone of the 2nd seam, the most common plant remains (Akhmetiev 1993, Akhmetiev and Golovneva 1998) are stems and rhizomes of *Equisetum*, fronds of *Onoclea* and seed cones of Pinaceae. The alternating tuffitic claystone contains masses of foliage shoots of *Metaseuqoia*, with additional *Denstaedtia*, *Fokieniopsis (=Ditaxocladus)*, *Cryptomerites*, *Amurocyparis*, and much fewer remains of Musci, *Equisetum*, *Onoclea*, and *Corylites.* In the dark grey-green tuffitic claystone of the 6th seam, the most abundant plant fossils are remains of *Metasequoia* (more than 100 specimens) and *Corylites*. Less abundant (10–15 specimens) are *Dennstaedtia* and *Onoclea*, *Amurocyparis*, *Equisetum* and two specimens of *Trochodendroides arctica*. The 9th seam is poor in fossils, with only *Metasequoia* and *Corylites*. The soil floor of the 11th seam is different, covering coarse-grained cross-bedded sandstone. Besides fragments of *Equisetum*, also several leaf fragments of *Ginkgo*, several infructescences of *Nyssidium* and masses of large leaves of *Trochodendroides arctica* and *Metasequoia* were recovered there. The 13th seam yielded abundant remains of *Onoclea*, while in the 20th seam only fragmentary stems of *Equisetum* were recovered. The finest-grained, partly lignitic tuffitic claystone contains an assemblage of *Metasequoia – Corylites.* This assemblage repeatedly occurs throughout the section with usually co-occurring *Amurocyparis*, *Fokienopsis* (= *Ditaxocladus*), and *Dennstaedtia* and represents ancient riparian vegetation. *Onoclea* and *Equisetum* may form uniform concentrations, the former in the fine-bedded deposits of swampy lowlands, the latter in various facies typical of both lowland swamp and levee habitats. Mass occurrence of *Corylites*

Text-fig. 7. Tuffitic argillites and coaly argillites with plant fossils near the bottom of the plant-bearing beds at the Malo-Mikhaylovka locality.

and *Trochodendroides* are always connected with *Metasequoia*. Leaves with *Trochodendroides* associated with *Ginkgo* are characteristic of the seamlet floors consisting of coarse-grained deposits, where most leaf fossils are fragmentary, obviously transported from distant surroundings of the basin and river levees. Also solitary specimens of *Cryptomerites*, seed cones and needle leaves of *Larix* relate to the allochtonous origin of this assemblage and longer transport.

The Malo-Mikhaylovka assemblage (Plate 1) is with respect to its ecotype similar to the Tsagayan flora from the Zeya-Bureya Basin (Kryshtofovich and Bajkovskaya 1966, Krassilov 1976, Akhmetiev et al. 2002). Although the dominant elements of the Tsagayan assemblage are *Trochodendroides* and *Taxodium* while at Malo-Mikhaylovka *Metasequoia* and *Corylites*, both assemblages obviously correspond in age, i.e. the Danian, because of the presence of other shared elements, e.g. *Equisetum*, *Onoclea*, *Ginkgo*, *Fokieniopsis* (= *Ditaxocladus*), *Nyssidium* etc.

Takhobe

The stratotype section of the Takhobe Formation is located in the central part of Sikhote-Alin'. This formation corresponds in age with Malo-Mikhaylovka. The fossiliferous plant-bearing levels are exposed in the lower part of the left slope of the Sobolevka (former Takhobe) River valley about 25 km from the mouth (Text-fig. 2). They are represented by tuffitic silts intermixed between tuffs, tuffites, which are underlain by lava flows and pyroclastics of the Samarga Formation and overlain after a distinct discordance by basaltoid lava flows probably of Miocene age (?). The fossiliferous deposits arose in a small piedmont lake below a volcano of the "Central Type" 5–6 km to the north from its top. The section on the eastern flange of the fossiliferous lens, ca. 50–60 m thick, includes the following layers:

1) Tuffites and tuffitic siltstones light grey and brown grey, thin-bedded – 12 m thick.
   The plant-bearing level is situated 1.2 m above the base and is covered by coarse-grained tuffs of white and light grey kaolinitic quartzose porphyrites.
2) Tuffite and ash tuffite, dark brown, thin-bedded, weathered – 9.5 m thick.
   It represents a correlation horizon extending laterally over 100 m.
3) Interfingering lenses and beds of fine-grained tuff, tuffite, sandstone and siltstone, each of 0.1 to 0.7/0.8 m thickness.
4) Acidic tuff interchanging with layers of tuffitic sandstone and siltstone – 14 m thick.
5) Coarse to medium-grained rhyolithic tuff, containing rock fragments of various effusive rocks, devitrificated glass and fragments of the Mesozoic from the folded basement.

The Takhobe plant assemblage (Table 1, Plates 2, 3) is par-autochthonous. Plant remains do not form a typical leaf bed but are irregularly scattered within the rock. Leaf fossils are orientated parallel to the bedding planes, are well preserved, not curved or rolled up in contrast to other sites in volcanic settings. The leaf blades are large, in broad-leaved elements averaging 5–15 cm and more. A dominant element of conifers is *Metasequoia* (35%). The angiosperms are well diversified (more than 10 morpho-species), dominant being *Ulmus furcinervis* and *Trochodendroides arctica*. The Takhobe plant assemblage represents an analogue of the younger Tsagayan flora from the Zeya-Bureya Basin in Priamurie, approximating in age to the Tsagayan and Kivda floras, the youngest floras of the Tsagayan complex, probably of Danian and Zelandian age. In general, the Takhobe flora is comprised of various Betulaceae including reproductive organs.

Taxa listed in Table 1 are only those represented in the collection of Akhemtiev. In addition to his results, more information is also available from the previous studies of Borsuk (1952), Ablajev (1974) and S. I. Nevolina (personal communication). In view of these studies the full list of the flora of Takhobe includes 52 species, among them 15 gymnosperms belonging to 13 genera and 36 species of angiosperms. Ablajev reports *Nilssonia gibbsii* from this location, which is the second record of *Nilssonia* in the Danian floras of the Far East (Ablajev 1974). The first record of *Nilssonia* was published by Krassilov (1970) from the Boshnyakov Formation of Sakhalin.

More than 70% of the collected specimens belong to *Metasequoia occidentalis, Cupressinocladus sveshnikovae,* seeds or rare shoots of the Pinaceae, *Trochodendroides arctica, Ulmus furcinervis,* foliage and reproductive organs of the Betulaceae. Seeds of the Pinaceae exhibit a high diversity and frequency, co-occurring with shoots of *Pinus, Elatocladus* and *Torreya* and also of some angiosperms (*Fagopsis, Betula*) belonging to representatives of slope vegetation. Hence, the site appears polytopic. The vegetation on the shores of the water was periodically buried by ash rains and other volcanic products and formed subautochthonous assemblages that include leaf remains of cf. *Carya* sp., *Menispermites, Lindera, Platanus nobilis, Protophyllum reticulatum, Sorbus* sp., *Rhus* sp., *Tiliaephyllum tsagaianicum, Nyssa bureica, Viburnum* etc. A mixture of Cretaceous elements (*Nilssonia, Elatocladus, Cupressinocladus, Protophyllum*), with plants more common in Cenozoic floras (*Davidia, Sorbus, Fagopsis, Lindera*) is a characteristic feature also of other Danian floras in the Russian Far East.

Zerkal'naya River (former Tadushi)

The third locality of the ancient branch of Southern Sikhote-Alin' was described from the uppermost part of the right bank of the Zerkal'naya River facing the village Ustinovka 0.1 km from the quarry of the same name (Text-fig. 2). The fossil-bearing lens is about 200 m long and 5 m thick and is wedged into acidic volcanites of the Bogopol' (= Takhobe) Formation, which arose from the Bogopol' Central Volcano, fragments of which are preserved in the opposite side of the Zerkal'naya River valley. The base of the fossil-bearing section is formed by welded tuffs. It is overlain by acidic tuff 5 m thick, variegated red-blue-greenish in colour, partly coarse-grained also containing angular fragments of volcanic glass. Higher up, a layer 3–3.5 m thick of kaolinic fine- or medium-grained tuff continues the section, towards its top alternating with fine-grained tuffites. The upper layer in the section consists of alternating ash tuffs, tuffitic sandstone, quartzone sandstone, light deposits including plant debris and leaf impressions, which are well preserved and orientated parallel to the bedding planes. The plant-bearing layer is overlain by fine-grained tuff (2.5 m thick) and a basaltoid lava flow above belonging to the Eocene Suvorovo Formation. Inside the Ustinovka quarry, the fossil-bearing deposits are more coarsely grained, they contain only catkins and fruitlets of *Betula*, branches and seeds of *Pinus* and leaf fragments. The fine-grained deposits in the upper positions yielded a more diversified flora with dominant being twigs of *Metasequoia*, leaves of *Ulmus furcinervis, Betula sachalinensis,* ?*Alnus* and fragmentary foliage of *Sichotaealiniopteris acuminatus* (obviously belonging to a rosaceous plant similar to those defined from the Eocene of the western USA by Wolfe and Wehr 1988). The following plant fossils were recovered as additional elements: foliage and seeds of *Pinus, Picea, Tsuga,* twigs of *Cupressinocladus sveshnikovae*, foliage of *Trochodendroides arctica* and leaflets similar to *Carya* (Plate 3).

The three sites described above belonging to the Senonian – Danian part of the volcanic belt, share various elements of the East Asiatic Tsagayan ecotype, in spite of individual character of each of them. In general, several elements appear as basic: *Metasequoia* associated with various other conifers, ancient Betulaceae, particularly *Betula*, *Corylites*, the former represented by leaves, catkins as well as fruits, Ulmaceae represented by *Ulmus furcinervis* and *Trochodendroides* with *Nyssidium* fruits. All listed taxa occur in the Upper Tsagayan Fm., in particular in the productive Kivda coal-bearing beds of the Zeya-Bureya Basin.

The Near-shore Andesitic-basaltoid Belt floras of the Eastern Sikhote-Alin' (Eocene to Neogene)

More than 100 volcanic centres were described from within the Near-shore Volcanic Belt in various states of preservation. They belong to early genetic and morphological types of volcanic products, widely variable in size and composition, in which basaltoid lava flows and pyroclastics prevail. Only general aspects are mentioned, without details.

Shield and gently sloping volcanoes of the Central Type with extrusive necks (Text-fig. 4) prevail, which may extend over 10 km or more, as well as linear trench volcanoes, cumulo-volcanos (cupoles of lavas), scoria cones, lava flows etc.

Clastic deposits connected with the volcanic facies and deposits consisting of weathered volcanic products are widely distributed on the periphery of the volcanoes and attain maximum thickness in the trough structures. Three groups can be recognized according to their type: 1) Plant-bearing deposits that originated before volcanic activity within the ancient river systems (e.g. site Sonje, Text-fig. 2). 2) Deposits synchronous with volcanic activity beside volcanic products (tephroides, pyroclatsic-tephroide products, tuffs, tuffites etc.); such volcano-detrititic strata form a manifold facial complex within or on the periphery of volcanic bodies and originated during volcanic phases. 3) Deposits that arose after volcanic phases or between longer gaps in volcanic activity, where clastic and cemented parts of deposits form a greater proportion in comparison with volcanic products.

In this part of our account, the alluvial and slope deposits of the volcanic belt are not discussed because they usually do not contain plant remains. More interesting are deluvial mud streams and fills of dry river valleys, which were previously mostly interpreted as tuffaceous agglomerates. Coarse-grained lahars usually form narrow stream bodies, 1–50 m in thickness, as fills of gorges. At the end of one of such lahars, one of most interesting plant-bearing localities, Siziman (Text-fig. 2), was discovered. Its fossiliferous bed was buried under ash layers. Similar lahars are exposed on the coasts of the Tatar Strait between the Sonje and Dembi bays, where rich localities of fossil plants also arose (Text-fig. 2). Characteristic features of lahars are the lack of bedding and irregular variable size of grains, in which basaltoid fragments prevail. To the north of the Bui Bay near the plant-bearing tuffaceous clastic lens, lahars form deposits 70–80 m in thickness and occur along the shore for a distance of 400–600 m. They contain 5–10 cm large fragments that consitute about 15% of the whole rock; rare blocks may attain 0.5 m in diameter. Ash and sandy layers form lenses up to 10 cm thick.

Alluvial deposits are common in the Near-shore Belt. They form layers or lenses from 0.1–0.2 m to 20–30 m in thickness. Facies of fluvial origin are more wide spread than those of the flood plane, although the latter are more interesting considering occurrence of plant fossils. Angularity of sedimentary particles varies. It may be very complete, requiring transport for longer distances or a longer period of deposition in a high energy environment. River and lake or lacustrine swampy facies are usually intimately connected. Not of great thickness and orientation within the sections indicates that river deposits arose in temporary river systems of various degrees. Such deposits were always connected with erosion deposits.

Siziman

A series of volcanic strata with plant fossils crops out near the northern end of the Siziman Bay on the Nitusi Cape, stretching into the Tatar Strait (Text-fig. 2). It is located on the southern slope, where it remained preserved having been sheltered by andesite-basaltoid lava flows. From its base upwards, it consists of lava flows and layers of pyroclastics of the basic and medium types. Coarse-grained pyroclastic layers are buried in tuffaceous matrix and interchange with lenses of lahar flows, which came from ravines on slopes of the volcano. Only rarely within the section lenses of ash tuff and thin laterally limited intercalations of tuffogenous deposits occur. Plant fossils, often preserved in their original living position (Text-fig. 9), are scattered in the tuff.

The complete section of the volcanic body (Text-fig. 8) can be characterized as follows:

1) The base of the section is formed by basaltoid zeolitizied breccias – 9 m thick.
2) A complicated layer of a subaquatic volcanic body, followed by stone-gravel lahar flows; tuff layers include fragments of basaltoids of various size and plant remains in original position, bedded tuffogenous deposits in lenses of up to 5 m thick also containing plant remains (80–85 m thick). This entire subaquatic volcanic body, which completely crops out in the Nitusi Cape, consists of the following parts:

   A– A lahar flow begins at its basement with fragments of different size of andesite-basaltoid composition, including pyroclastics. Only rarely bigger blocks and pebbles (up to 3 m in diameter) occur together with lenses of light brown, coarsely parallel-bedded sand and clay of various grain size and thin, devitrificated ash. The layer contains remains of *Equisetum arcticum, Dryopteris* sp., *Metasequoia occidentalis, Betula* sp. and *Platanus* sp. (34 m in thickness).

   B – Dark brown-grey tuffs that interchange with bedded tuffogenous–clastic deposits. In coarser parts, gravel material is scattered (4.6 m in thickness).

   C – A gravel layer with fragments of magmatic rocks cemented by tuff material (1.2 m in thickness).

   D – A layer of dark brown-grey tuffogenic sandstones and siltstones gradately bedded (2.5 m in thickness).

   E – Tuffs and tuffogenous sandstones including rock fragments of various size, which interchange with lenses of bedded tuffogenous–clastic deposits and lahar breccias (40 m in thickness).

Text-fig. 8. Basalts, agglomerates and coarse tuffs (dark) and plant-bearing coarse tuffaceous sandstones with fossil plants (light) on the Nitusi Cape, Siziman locality.

Text-fig. 9. Lower part of a fossil woody stem in the tuffaceous beds at Siziman.

   Near the base of the tuffogenous layer, there occur permineralized (opalized) axes, branches and leafy shoots in original living position as well as leaf remains of *Zelkova,* Leguminosae, numerous wood fragments in various degree of permineralizasion.

3) Southern slopes of the volcanic body are formed by andesite-basaltoid lava flows with columnar jointing, which cover, after a hiatus, weakly weathered underlying volcanites (more than 30 m in thickness).

The dating of the Siziman flora to the Oligocene has been confirmed by radiometric dating of the andesite-basaltoid block from layer 2 which corresponds to 30.7±2.3 Ma. Andesite-basaltoids covering the subaquatic volcanites after a hiatus are dated as 14 Ma. All radiometric data were obtained from total rock probes (K-Ar) in the labs of the Far East Geological Department, Vladivostok (analyser T.G. Koval'chuk).

Although the first collections of plant remains from the Nitusi Cape were made at the beginning of the 1950s, during geological mapping, the obtained palaeobotanical data remained preliminary and unpublished. In 1963, when geological mapping sheet at the scale of 1:200 000, adjacent to the Siziman area was being prepared, Akhmetiev collected additional new fossil material from different parts of the above-described section, namely 1) plant remains from the psammitic tuffs buried in living position during ash rains, in particular leafy shoots, fragments of vertically orientated axes, wood fragments, isolated leaves of trees, shrubs, lianas and ferns; 2) plant fossils from tuffaceous–clastic deposits, where leafy shoots of Taxodiaceae and leaves of dicots are preserved as impressions parallel with the bedding plane.

Akhmetiev (1988, 1993) gave general characteristics of the site and identified more than 20 taxa including descriptions of new elements. The collections of wood made by Akhmetiev were studied by I.A. Shilkina (Botanical Institute RAN) who identified *Picea* sp. and *Cedrus* sp. Later the collections were studied by Blochina (1985) together with her additional collections. She identified conifers belonging to the Pinaceae (*Pinus, Picea, Larix*), Taxodiaceae (*Sequoia, Metasequoia*) and Cupressaceae. Fructifications and foliage shoots of the mentioned genera are given in the published work quoted above.

In the first report (Akhmetiev 1978) the following elements were published: *Equisetum arcticum, Onoclea grandifolia, Dryopteris sp., Picea* sp. (twigs, seed cones, seeds), *Larix* sp.(seed cones, twigs), *Metasequoia occidentalis, Thuja* sp., *Magnolia* sp., *Menispermites* sp., *Populus* sp., *Alnaster sachalinensis, Betula* sp., *Corylus* sp., cf. *Castanea longifolia, Zelkova* sp., Leguminosae gen. indet. (foliage, fruits), *Pueraria sizimanica, Wistaria sichote-alinensis, Platanus* sp., *Acer* sp., *Vitis* sp. and *Viburnum* sp.

In the middle of the 1980s, the site was revisited by A.I. Ablajev (Ablajev 1985), who added several new taxa to those previously known: *Lindera* sp., *Laurophyllum* sp., *Castanopsis* ex gr. *kazakhstanensis, Mallotus* sp., *Byttneriophyllum* sp. (probably *Plafkeria* sp.).

The Siziman flora (Plate 4) is typically polytopic, where some angiosperms, partly evergreen, belong to subtropical elements. They mix with conifers and Betulaceae, which represent temperate vegetation and reached the fossiliferous layer from various altitudinal zones. In the higher part of the slope, coniferous and mixed coniferous small-leaved forests thrived. The forest of the lower zone consisted of taxodioid conifers and broad-leaved elements including lianas (*Wistaria, Pueraria*) and also ferns and *Equisetum* in the ground floor vegetation.

The Oligocene age of the Siziman flora has been corroborated by radiometric data, as detailed above.

Sjurkum

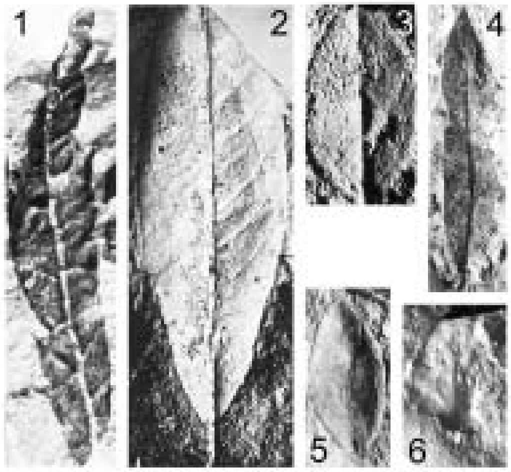
A sub-aquatic complex of volcanites that originated from products of volcanoes located eastwards, crops out about 8 km south-west of the Sjurkum Cape northwards from the town of Sovetskaya Gavan’ (Text-figs. 2, 10). It is deposited on basal psephitic and coarse-grained psammitic conglomerates (8–10 m thick).The pebbles in the conglomerate consist of basaltoids and andesite-basaltoid rocks. The complex consists of 5 components:

1) Volcanogenic-clastic breccias, which are products of lahar mud streams – 60–70 m thick.
2) A layer of bedded tuffogenic-clastic rocks, which interchange with lahar streams.
3) Andesitic breccia and agglomerates, which consists of lumps and fragments of “welded tuffs”, andesites with light-coloured crusts of burning. The spaces between lumps are filled with loose tuffaceous cement.
4) Andesitic basalts with flaggy jointing (5–7 cm) – 25–28 m thick. It was dated by the K-Ar method as 16 Ma (Far East Geological Department, Vladivostok (DVGU) analyzed by I.I. Kovalčuk).
5) Agglomerate and agglutinates of basalts and andesite-basalts. Within lumps and fragments of many rocks from underlying strata are “inclusions and pockets” of agglomerates, the contact between them is not flat.

Still higher in the section, depending on the approaching volcanic centre, interchanging streams of lavas and accumulation of breccious lavas can be encountered. The lava streams of anadesito-basalts prevail – 400 m thick.

Plant-bearing layer 2 shows a rhythmic texture recalling “bedded cake”, consisting of lenses and interlayers of tuffs, tuffogenic sandstones, tuffogenic siltstones, and white devitrificated fine ash and lahar streams. In the middle of the layer is and siltstone band with lignite lenses (0.15 m). The white ash tuff (0.5 m thick) 4 m above the floor yielded *Equisetum* sp., *Taxus* sp., *Carpinus* sp. (fruits), *Salix* sp., *Myrica vyvenkensis* and *Vaccinium* sp.

Above the plant-bearing layer are banded brown-red tuffs (14 m thick) with lenses of lahars and white ash with rare fragmentary leaves of angiosperms, which are folded, rolled up and torn. In one ash layer a leafy twig of *Alnaster sachalinensis* occurred along with isolated leaves of the same species. Still higher in the sections over layer 2, above a thin silty band (0.15–0.20 m) there again appear tuffs interchanging with tuffaceous sandstones (15 m), which yielded leaves of *Rhododendron lancifolium*. In the roof of this layer a band of coarse-grained basaltoid tuff (2–2.5 m) occurred.



Text-fig. 10. Typical elements of the flora of Sjurkum.
1 – *Myrica vyvenkensis* Akhmetiev, leaf, × 0.7; 2 – *Rhododendron lancifolium* Akhmetiev, leaf, × 0.7; 3, 4 – cf. *Vaccinium* sp., leaves, × 0.8 and 1; 5 – *Salix* sp. (ex gr. *S. glauca* L.), leaf, × 0.7; 6 – *Carpinus* sp., involucre, × 1 (coll. Geol. Inst. RAS Moscow).

Among the 328 plant fossils collected, 59 specimens belong to small-leaved *Myrica vyvenkensis*, 53 specimens to microphyllous *Vaccinium*, 51 specimens to *Alnaster sachalinenesis*, 41 specimens to *Rhododendron lancifolium* and 20 specimens to *Salix* sp. Single specimens belong to *Equisetum, Osmunda sachalinensis, Carpinus* sp. (fruits), cf. *Cercidiphyllum*, isolated leaves of *Taxus* with a characteristic arrangement of stomata and winged seeds of Pinaceae gen. (Text-fig. 10). Transported clastic material originated from the upper parts of the active volcano. The prevailing forms are small-leaved, mostly shrubs thriving in a temperate climate, possibly due to altitudinal difference of the relief. In contrast to the Siziman site, where cold and thermophilous elements are mixed, the flora of Sjurkum is the most cold-loving sub-autochthonous complex of Oligocene age among others known from the Near-shore Belt.

Sites of the Tatar Strait shore south of Nel’ma (Eocene to ? Early Miocene)

The part of Sikhote-Alin’ between the Sonje and Dembi bays south of the town of Sovetskaya Gavan’ exposes the most complete section of the first phase of volcanic strata of the Near-shore Volcanic Belt (Text-fig. 2). This area is most important considering the fact that three of the four floristic complexes distinguished in Sikhote Alin' have been characterized there. They are connected with subaquatic volcanites of the first phase in the Near-shore Volcanic Belt. Its total thickness reaches over 1000 m and forms a single volcano-tectonical unit, whose wing is built of monoclinally lying volcanites inclined to the north. The main centre which produced most of volcanic material was the volcano Ozernyi, situated west of the Dembi Bay and also stretching into the shore line area. In the Bui Bay, the monoclinal unit became more complicated by an ascending fundament of granitioides of the Bui Massif that originated from the Cretaceous/Tertiary boundary. These rocks are coeval with the volcanites of Senonian – Danian age.

The scientist who first brought evidence of the three floristic complexes was V.G. Plakhotnik (1962) who described a composite section of volcanites together with floral lists of three sites – Sonje, Bui and Dembi (Text-figs. 2 and 11). His evidence was produced on the basis of preliminary identification by M.O. Borsuk, who disposed of the collections made in 1960 by V.G. Plakhotnik, A.S. Tishina and M.A. Akhmetiev. Akhmetiev made additional collections in 1964 from all three collecting sites and described and illustrated the material in his Thesis and several later papers (Akhmetiev 1965, 1972, 1973b, 1974, 1988) plus a monograph (Akhmetiev 1973 a).

All three floras – Sonje, Bui and Dembi – differ from each other being situated at different levels of the volcanic complex. The upper member of the section consists of subaquatic lava flows of andesite-basalts and andesites and represents the final phase of activity of the Ozernyi volcano. They cover discordantly various parts of the subaquatic volcanic complex, they are also penetrated by dacitic volcanites which contain xenolithes of underlying Early Palaeogene granitoids. In the Miocene, due to interruption of the first phase of volcanic activity in the Near-shore Belt, a network of the river system originated. In the Pliocene, this system was buried by plateau basalts of the Sovgavan' Formation and its traces can be assumed by occurrences of sandy pebble alluvial deposits between the andesites of the Kizi Formation and the floor of the plateau basalt flows.

The following text describes the section of the subaquatic andesite-basaltoid complex in detail and characterizes the three floristic complexes of the section, focusing on the youngest and most diversified assemblage at Dembi.

Sonje Bay (Late Eocene)

This part of the Near-shore Belt is the oldest. It crops out at the end of the Sonje Bay. The strata originated in subaquatic conditions, as apparent from the basaltoid pillow lavas similar to the classical type (Text-figs. 2 and 11).

In the basement of the section are developed:

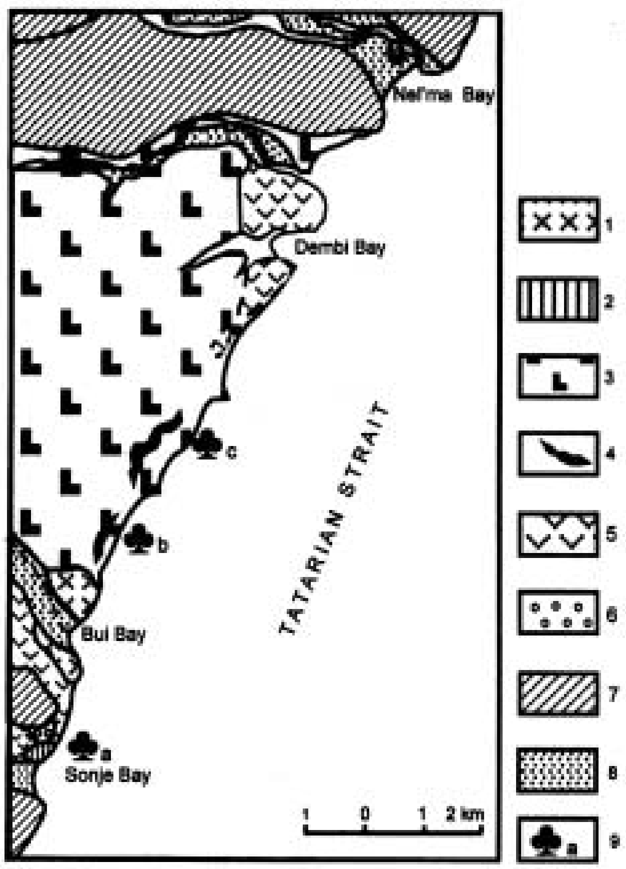
1) Rhyolites and ignimbrites (68 Ma by radiometric dating), which are products of the East Sikhote-Alin' Senonian – Danian belt.
2) The weathered zone of ignimbrites is covered by products of lahar streams consisting of chaotic fragments and lumps of andesite-basalts and basalts, cemented by fine-grained tuffogenic-clastic material – 10 m thick.
3) Several layers of violet andesitic tuffs embracing – 16.5 m thick.
4) Rhythmically interchanging yellow aleurites and argillites with grey sandstones. More fine-grained parts silicified to various degrees. Plant remains on bedding planes within the rhythmic layers each 0.2–0.3 m thick – 6 m thick in total.
5) Fine-grained, light yellow hyaloclastites, transferred into palagonites, including pillow lavas – 7.5 m thick.

The total thickness of the Sonje subaquatic strata is ca. 40 m.

Small consolidated conglomerates of the Pliocene occur above, which are overlain by flows of plateau basalts.

Layer 4, including plant remains, consists of volcano-terrestrial deposits that concentrated in small lake or slowly running water body on the piedmont of the volcano that periodically exploded. The lake itself belonged to an ancient hydrological system that functioned until the origin of the Near-shore Andesite-basaltoid Belt.

In contrast to the younger volcanic levels, the Sonje assemblage includes some ancient elements characteristic of Early Palaeogene floras: *Trochodendroides arctica, Cocculus ezoanum, Platanus* sp., *Fagopsis* sp., *Davidia* sp.,



Text-fig. 11. Geological map south of the Nel'ma Bay. 1 - granodiorite (Early Palaeogene); 2 – Eocene andesitic and dacitic tuff with plant-bearing argillitic lenses; 3 – Late Eocene to Early Miocene andesite-basalt (Kizi Volcanic Group); 4 – tuffogenous sedimentary plant-bearing lenses with plant fossils; 5 – Dacite neck (Early Oligocene) 1 km south of the Dembi Bay; 6 – Pliocene pebbles and conglomerates; 7 – Plateau-basalts (Sovgavan' Formation, Late Neogene–Quaternary); 8 – Quaternary alluvial deposits; 9 – localities with fossil plants: a – Sonje, b – Bui, c – Dembi.

Plafkeria sp. etc. Various gymnosperms include more than ten taxa: *Ginkgo, Taxus, ?Podocarpus, Pinus* spp. (shoots, seeds)*, Cryptomeria* sp*., Metasequoia occidentalis*, *Taxodium olrikii*, ?*Cunninghamia* sp., *Thuja* sp. and *Thujopsis* sp. The dominating conifers are *Pinus* and *Metasequoia*, dominating angiosperms *Trochodendroides*, *Cocculus* and *Fagopsis*.

The Sonye collection contains more than 300 specimens. 27 species were identified belonging to 23 genera. Some of the poorly preserved specimens were not identified. Besides those listed above, the taxa represented by single specimens are *Alnus onorica* Borsuk*, Betula* sp*., Carpinus* sp.(morphologically near to modern *C. laxiflora* Bl.), *Fagus* sp. (poorly preserved leaves and cupules) and *Acer* sp. (leaves and fruits). The flora of Sonye differs only in abundance of conifers from others of a similar age in Primorie and Sakhalin which also include *Trochodendroides*, *Cocculus* and *Plafkeria*.

The flora of Sonje is a typical mesophytic assemblage from the Far East Late Eocene. It reflects the existence of warm temperate mixed coniferous and broad-leaved forests that included various conifers. Its content is characterized by ancient elements typical of the Early Palaeogene, which did not survive in younger floras.

Bui Bay (? Late Eocene – Early Oligocene)

North of the Bui Bay, an isolated section of the same name belonging to the Subaquatic Andesite-basaltoid Belt crops out (Text-figs. 2, 11). The fossiliferous layer there attains not more than 3–4 m and is wedged between basaltoid lava flows (on the base of the section) and andesite-basaltoids that overlie it. The general thickness of the Buy complex does not exceed 50 m. Plant remains were collected from black quartzose tuffitic argillites, indistinctly bedded and characteristic of shaley fracture. The intermediate position of the Bui flora between those of Sonye and Dembi is corroborated both in the floral composition and the stratigraphical position of the site within the subaquatic Andesite-basaltoid Belt. Of the 90 available specimens, a larger proportion belongs to the angiosperms. Akhmetiev and Vikulin (1995) described a new species of *Macaranga* (Euphorbiaceae) from Buy Bay and Akhmetiev and Manchester (2000) recorded *Palaeocarpinus sichote-alinensis* there. The flora includes 29 species belonging to 20 genera of 16 families. Conifers (shoots and winged seeds) are represented by 12 specimens (*Pinus* sp*., Tsuga* sp*., Thuja* sp*.).* Among angiosperms *Tilia* sp. (15 specimens) and *Macaranga* sp. (9 specimens) are represented most frequently and also *Thuja* of the conifers. Of the plants characteristic of the Oligocene and Early Miocene, *Craigia oregonensis*, *Plafkeria* sp., *Acer ezoanum*, *Carpinus subcordata*, *Fagopsis* sp., *Cercidiphyllum crenatum*, ?*Platanus* sp. and others were recovered (Plate 5). The small size of the collection makes it difficult to correlate it with the other floras of the Subaquatic Andesite-basaltoid Belt. It predates the flora of Dembi collected higher in the section; it does not contain any relicts of the Early Palaeogene, such as *Trochodendroides arctica* and *Cocculus ezoanum*. The Bui flora characterizes the transition between the Eocene and the Oligocene or is of Early Oligocene age.

Amgu (Oligocene)

Southwards from the Bikin basaltoid plateau, the southern continuation of the Subaquatic Andesite-basaltoid Belt is spread within the Near-shore Volcanic Belt. The first author (M. Akhm.) collected fossil plant remains from two sites; one of them is situated 12 km from the mouth of the River Amgu which enters the Tatar Strait at the village of the same name (Text-fig. 2), the second lies ca. 4 km north of the village Velikaya Kema.

The Amgu flora was recovered and studied firstly by Kryshtofovich (1921). He described 19 taxa, of which 9 are representatives of the gymnosperms. All subsequent collections corroborated a great proportion of these plants, namely conifers, in this flora. In the 60s and 70s of the last century, further collections were made at the Amgu sites by R.S. Klimova (Rybalko, Ovechkin and Klimova 1980) and Akhmetiev (1973a, 1988, 1993).

As in other areas of the Southern Sikhote-Alin' far from the sea shore, dense taiga forests, that covers sparsely the exposed slopes and valley edges, make it impossible to study in detail the geological section of the subaquatic volcanic rocks there and recognise facially the fossiliferous layers. Also numerous large land slides of blocks of effusive rocks along soft clayey layers disturb the sections. Therefore interpretations of the geological structure of volcanites on the right shore of the Amgu River vary according to views of the individual specialists.

Volcanic rocks of andesite-basaltoid composition lying at the base of the Near-shore Belt represent lava flows and coarse-grained pyroclastic rocks. Lava flows may often occur within the section. They lie on the denudated surface of the Senonian – Danian volcanoes and intrustions, which is fixed (and can be clearly seen) in shore exposures of the Belkin Cape south of the Amgu village. This cape divides the Tatar Strait from the Japan Sea. The radiometric age of the anadesite basalts was determined as 47.0±1.2 Ma according to the total sample (K-Ar) collected by the first author (M. Akhm.) from the floor of a lava flow in the Belkin Cape (laboratory IGEM RAM, analysed by M.A. Arakelyants). This effusive body of almost horizontal orientation continues uninterrupted from the mouth of the Amgu River along its right hand shore up to the fossil locality. Its thickness is not more than 50–70 m, as at some places on the base of slopes, the Senonian–Danian dacitic tuffs and granodiorites crop out. The section enlarges only at a distance of 3 km from the locality, down towards the river mouth on its right hand shore, where first exposures of overlying tuffitic–clastic deposits (Granat Formation) of the fossiliferous layer appear. This formation attains more than 300 m in thickness. It contains two fossiliferous layers divided by a basaltoid flow; the thickness of the tuffitic –clastic deposits reaches not more than 100 m.

The section of the volcanic complex on the locality includes (from below):

1) Olivine basalts, fine porphyric, dark grey – 100 m thick. In the base of the valley below the fossiliferous layer only upper basaltoid flows are exposed.
2) Tufftic sandstones, fine – to medium grained, grey, including fragments of underlying basalts – 10 m thick.
3) Tuffitic claystones and siltstones, light brown, massive as well fine bedded, silicified, with shell fractions and

lenses of psephitic tuffs and hyaloclasts of basic composition. Plant remains occur in tuffitic claystone – 50–70 m thick.

4) Olivine basalts aphyric, dark grey, massive and bedded – 150 m thick.
5) Siltstones and claystones silicified, with admixture of fine ashes, bedded, with a lens of psammitic sandstone 10 m thick at the base – 30 m thick.

Collections from layer 2 include 47 species, belonging to 39 genera and 27 families (Plate 5). Out of 300 specimens, ca. 60% belong to gymnosperms, mostly to the Pinaceae – *Abies* (seeds), *Picea* (seed cones, seeds), *Pinus* (seed cones, needle fascicles of 5, 3 and 2 needles, seeds, not less than 3 species), *Pseudolarix* (foliage shoots, seed cone scales, seed cones), *Tsuga* (seed cones, seeds) and Taxodiaceae – *Glyptostrobus* (seed cones, shoots), *Metasequoia* (foliage shoots), *Taxodium* (foliage shoots) and *Sciadopitys* (isolated needles). In a few specimens *Ginkgo* (7 leaves) and *Thuja* (5 shoots) were recorded. Among ferns, a single pinna of *Osmunda sachalinensis* has been recovered and single remains of moncots. Among dicots more than 15% of specimens belong to *Alnus corylina*. Various shrubs and short tress belong to the Rosaceae (*Cerasus*, *Pyrus*, *Prunus*, *Sorbus* sect. *Aucuparia*, *Spirea*). The same group of understorey shrubs and trees is also represented by legumes (fruits, foliage), *Cercidiphyllum crenatum*, *Ilex*, *Celastrus*, *Ziziphus*, *Daphne*, *Styrax*, *Ligustrum*, cf. *Syringa*, *Lonicera* and *Viburnum*. Leaves of the Fagaceae (*Fagus*, ?*Castanea*) and Ulmaceae (*Ulmus*, *Zelkova*) occur in single specimens. The site arose in oxbow lakes or small lakes surrounded by volcanite masses and often dammed up lava flows and coarse grained pyroclastics. The plants recovered are mostly microphyllous and belong to slope vegetation, which is also seen in a great proportion of conifers. Evergreen plants are absent, as well as Early Palaeogene elements (*Trochodendroides*, ancient Platanaceae). From the other localities of the Far East, typical are well differentiated shrub forms, in particular Rosaceae; such a flora is known in the Oligocene of the Khoindzho Cape on Sakhalin. The site is composed of layers underlying the coal-bearing Lower Dui Formation with a Miocene flora (Akhmetiev 1974).

The flora of Amgu existed in conditions of a temperate seasonal climate, in a period before the warming in the Far East produced a typical flora of the "*Engelhardia* Beds", as elements of this flora were found higher up in the same section in the 5th layer by R.S. Klimova. The flora corresponds to the period of maximum warming during the formation of the Near-shore Volcanic Belt and includes *Comptonia*, *Engelhardia*, *Cinnamomum*, *Ilex*, *Ziziphus*, *Nyssa*, *Ampelopsis*, *Porana* (i.e. *Astronium* or *Chaneya*) and Fagaceae (Rybalko, Ovechkin and Klimova 1980). There are no doubts about the contemporaneousness with other subaquatic fossiliferous layers at Dembi and Velikaya Kema.

Velikaya Kema (Oligocene to? Early Miocene)

In the lowlands of the Velikaya Kema River, and near the village of the same name, as well as the basins of the rivers Peshchernaya and Listvennaya, only the middle and upper parts of the section of the first subaquatic masses of the Near-shore Volcanic Belt are exposed. They lie on the errosional surface of the Senonian – Danian volcanites. Here, as always in the case of volcanic-diatomites deposits, due to the development of landslides, it is difficult to follow the complete section of subaquatic masses. Only the sequence of individual layers can be suggested within the section (Text-fig. 12)

1) Basalts consisting of several flows, each 5–7 m thick – more than 100 m thick in total.

2) Agglomerates, coarse-grained tuffs, in block breccias of basaltoids, partly melted together – up to 15 m thick.

3) Tuffs of basic to middle composition replaced laterally by tuffitic conglomerate – up to 30–40 m thick.

4) Tuffs, tuffitic claystones, diatomites, primarily silicified clayey rocks. In this layer, plant fossils occur, particularly in the diatomites. In the floor are lenses of felsit-like rock – up to 50 m thick.

5) Conglomerates, tuffs – 30 m tick.

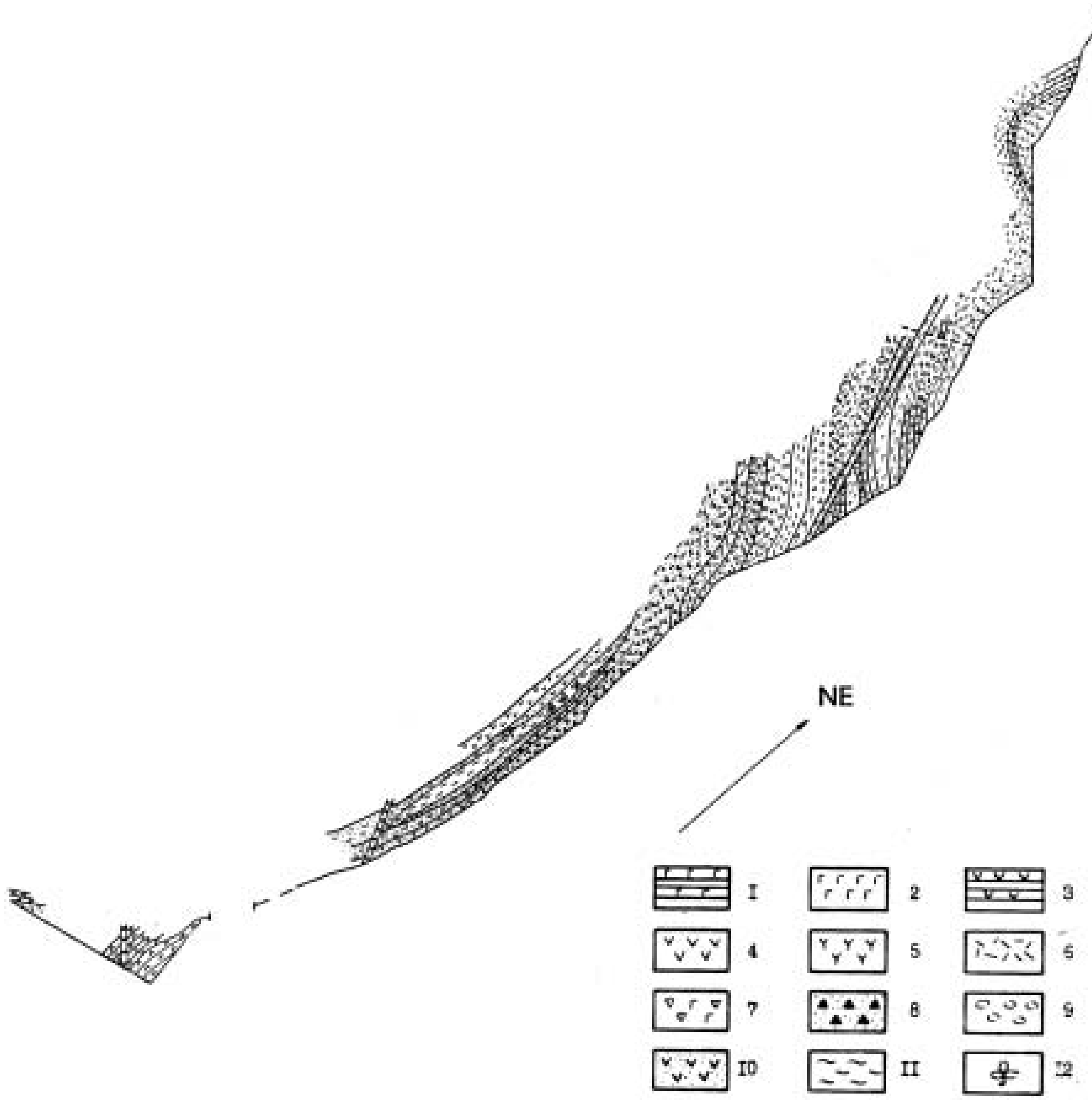
6) Andesitic basaltoids, bedded, finely porphyric – more than 30 m thick.

Layer 4, mostly composed of diatomites in its middle part, yielded approximately 50 species of fossil plants. They belong to *Equisetum* sp., *Ginkgo* ex gr. *G. adiantoides*, *Abies sikhote-aliensis* (shoots, seeds), *Abies* sp. (seeds), *Larix* sp., *Picea* spp. (single shoots and mass occurrence of seeds), *Metasequoia occidentalis* (shoots, seeds and pollen cones), *Calocedrus* sp. (shoots, seeds), *Comptonia naumanii*, *Alfaropsis* (= *Engelhardia*) *koreanica*, *Pterocarya castaneifolia*, *Betula palibinii*, *Alnus schmalhausenii*, *Carpinus subcordata*, *Carpinus lanceolata*, *Carpinus* ex gr. *tschonoskii* foss. (all remains of hornbeams represented by leaves and fruit bracts), *Corylus* sp., *Ostrya oregoniana* (leaves, fruit bracts), *Fagus stuxbergii*, *Fagus protojaponica*, *Quercus miocrispula*, *Quercus kodairae*, *Quercus miovariabilis*, *Zelkova tibae*, *Zelkova zelkovifolia*, *Cercidiphyllum crenatum*, *Sassafras subtriloba*, *Craigia oregonensis*, *Platanus aceroides*, *Spiraea* sp., *Ailanthus yesoensis*, *Acer miocaudatum*, *Rhus* sp., *Euonymus* sp. and *Diospyros miokeaki*.

Besides shoots of *Metasequoia* and seeds of the Pinaceae, other taxa occur rarely. At a frequency of 10–15 specimens, remains of *Calocedrus*, *Alfaropsis*, *Craigia*, *Carpinus*, *Ostrya*, various species of *Quercus*, *Comptonia* and *Ailanthus* are seen.

The flora of Velikaya Kema (Text-fig. 13), like that of Amgu, is mostly small-leaved and small-fruited. The latter is expressed particularly in fruit valves of *Craigia*, which are twice smaller than those of the same species from the locality Botchi. The burial of plant remains occurred near the shore line of a small lake of an area of not more than 2–3 km square, in which diatomites accumulated. Plant remains are not condensed in "leaf layers", but are usually scattered individually on bedding planes. Plant remains do not occur in the coarse-grained deposits.

The flora of Velikaya Kema is of the same age or similar to the other floras of the *Engelhardia* Beds of the Southern Primorie (Kraskino, Rettikhovka), The Near-shore Belt (Dembi), northern part of the Korean Peninsula and adjacent parts of Heilogjiang (China) (Ablajev et al. 2005). The age of the "*Engelhardia* Beds" was previously considered to be Early to Middle Miocene, but in recent years it was

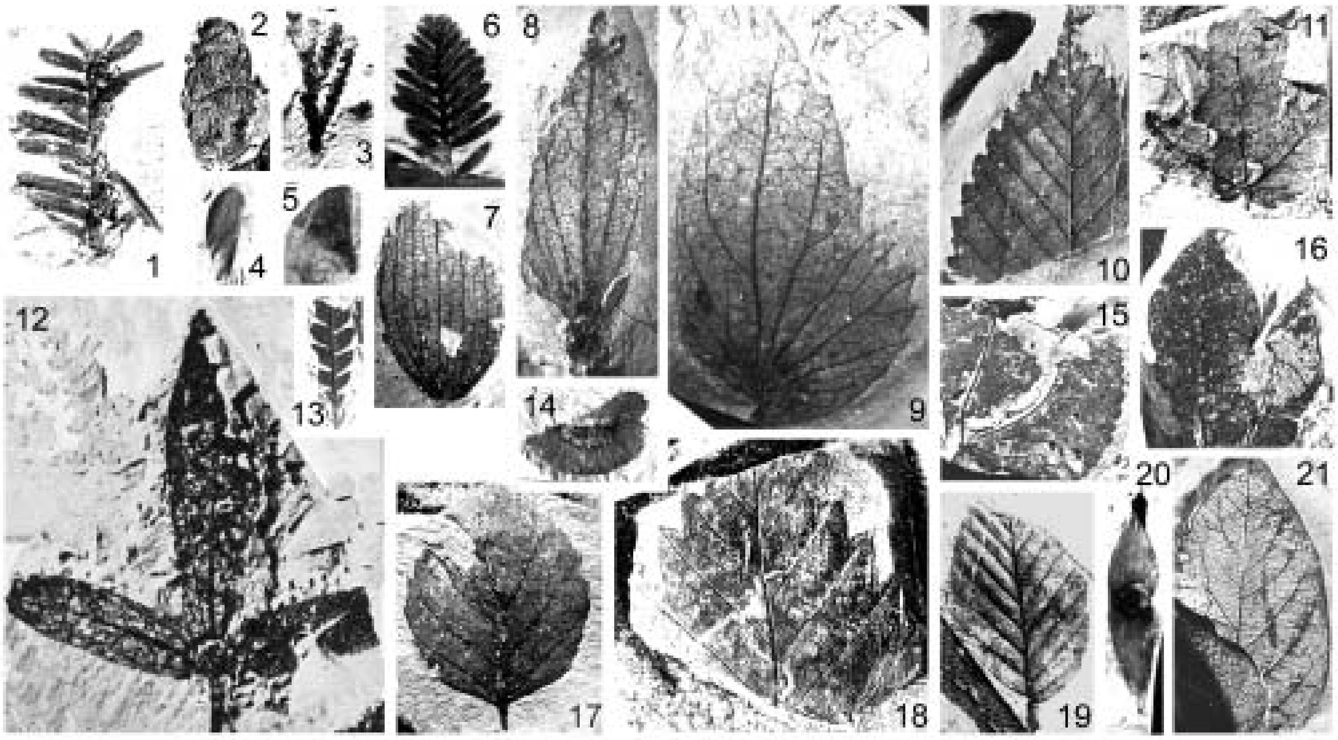


Text-fig. 12. Geological plan of the Velikaya Kema plant-bearing locality (4 km north of Velikaya Kema village). 1 – basalt with flaggy flows; 2 – massive basalt; 3 – andesite with flaggy flows; 4 – andesite-basalt; 5 – trachyte, 6 – felsite; 7 – agglomerate, basalt and andesite; 8 – tuff coarse-grained; 9 – conglomerate; 10 – thin layers of andesitic tuff; 11 – tuffite, tuffaceous argillite, diatomite; 12 – plant bearing levels.

revised. Today these floras are dated as Oligocene, or possibly at the beginning of the Miocene. This view is due to changes in radiometric dating of the Oligocene/Miocene boundary and stratigraphic correlation of marine complexes (in particular planktonic faunas) on the Oligocene – Miocene transition in the Japan-Sakhalin region.

Dembi Bay (Oligocene to ?Early Miocene)

The subaquatic volcanite complex south of the Dembi Bay covers the Bui complex which, gently dipping, falls towards the north. It starts with grey layers of hyaloclastites and pillow lavas of basaltoids, in total thickness not less than 50 m (Text-figs. 2, 14, 15). They were produced by explosions of the volcano Ozernyi, whose crater is situated 0.5 km SW of the bay. The hyloclasts and pillow lavas are overlain by a fossiliferous layer of tuffitic-clastic deposits and diatomites, ca. 10–12 m in thickness. It can be traced laterally to a distance of 150–200 m. This layer consists of diatomites, tripolis, opalilites, palagonite tuffs and thin interbeds of light devitrified ashes, tuffogenic sandstones and claystones as well as lenses of minor thickness of dacitic and rhyolitic tuffs – differentiated products of the volcano Ozernyi. The layer originated in a small lake in the short-time period when it was dammed up from the underlying volcano, which continued to be active as lenses of pillow lavas of andesite-basaltoids are present within the deposits. The tuffogenous-clastic layer is covered by hyaloclastics, which are analogous to those occurring in the lower part of the section at Dembi. Above the hyaloclasts are flows of flaggy andesite-basaltoid lavas, which form a cover up to 70–80 m thick and quickly decrease depending on the distance from the eruptive centre. In the floor of the andesite-basaltoid lava, a marker horizon occurs that divides them from the hyaloclasts. It consists of boulders



Text-fig. 13. Typical elements of the flora of Velikaya Kema (coll. Geol. Inst. RAS Moscow). 1 – *Abies* sp. 1, twig, × 0.7; 2 – *Larix* sp., seed cone, × 0.7; 3 – *Calocedrus* sp., twig, × 0.7; 4 – *Picea* sp., seed, × 0.8; 5 – *Abies* sp. 2, seed, × 0.7; 6 – *Metasequoia occidentalis* (Newberry) Chaney, leafy shoot, × 0.7; 7 – *Ostrya* sp., involucre, × 0.7; 8 – *Carpinus* sp. (ex gr. *C. cordata* Blume), involucre, × 0.7; 9 – *Carpinus* sp. 2 (ex gr. *C. tschonoskii* Maximovitch), involucre, × 0.7; 10 – *Ulmus* sp., leaf, × 0.7; 11 – *Acer miocaudatum* Hu et Chaney, leaf, × 0.8; 12 – *Engelhardia* (*Alfaropsis*) *koreanica* Oishi, ×; 13 – *Comptonia naumannii* Nathorst, leaf, × 0.7; 14 – *Craigia oregonensis* (Arnold) Kvaček, Bůžek et Manchester, capsule valve, × 0.6; 15 – *Cercidiphyllum crenatum* (Unger) R. Brown, leaf, × 0.7; 16 – *Sassafras subtriloba* (Konno) Tanai, leaf, × 0.7; 17 – *Dicotylophyllum* sp., leaf, × 0.7; 18 – *Quercus kodairae* Huzioka, leaf, × 1; 19 – *Carpinus subcordata* Nathorst, leaf, × 0.7; 20 – *Ailanthus* sp., fruit, × 1; 21 – *Diospyros miokeaki* Hu et Chaney, leaf, × 0.5.

Text-fig. 14. Dembi plant-bearing strata (4 km to the south of the Dembi Bay).

Text-fig. 15. Detail of the Dembi site.

and fragments of the underlying rocks cemented by opal matter mixed with a thin crust of effusives. To the north, where the flows of flaggy andesite-basaltoid lavas are absent, this marker horizon is overlain by agglomerates and breccias of dacites. Very near the Dembi Cape, the whole subaquatic complex is interrupted by a steep dacitic stock, with inclusions of fritting xenolites of Senonian – Danian granitoids, which form the basement of the volcano of Ozernyi. Radiometric age of the dacits was determined on the basis of the monomineral amphibole fraction – 33 Ma (analysed by M.A. Arakeliants, laboratory of the Institute of Geology of Ore deposits (IGEM RAN)).

In the tuffogenic-clastic layer, the plant remains occur in various kinds of rocks, mostly in diatomites (Text-figs. 14, 15). The collection includes more than 1000 specimens. Of them 220 belong to the gymnosperms. In total 74 species (Plate 6) have been recognized, belonging to 46 genera and 26 families. 16 taxa of angiosperms remain unidentified. The dominant components belong to the Pinaceae (8 specimens), Betulaceae (7 specimens), Fagaceae (9 specimens) and Aceraceae (5 specimens). Among gymnosperms most common are the remains of *Metasequoia occidentalis* (146 specimens), *Taxodium* (19 specimens) and *Glyptostrobus*

(13 specimens). The other elements are represented by single impressions (*Ginkgo*, *Tsuga*, *Abies*, *Picea*, *Pseudolarix*, *Thuja* and *Thujopsis*). Among angiosperms *Quercus ussuriensis* with dissected leaves dominates (35–40%), being the first colonizing the volcanogenic substrate after successive eruptions. The foliage of this oak is rather variable in form, like many living species of the Far East, and indirectly indicates the existence of possible hybrids. Other taxa recovered and represented by 5–30 specimens were : *Ostrya oregoniana*, *Carpinus subcordata* (foliage and associated fruits), *Fagus palaeocrenata*, *Castanea miomolissima*, *Castanopsis* sp., *Ulmus longifolia*, *Zelkova* sp., *Cercidiphyllum crenatum*, *Craigia oregonensis*, *Trapa* sp., Araliaceae gen., *Cercis* sp., *Rhus* sp., *Vitis* sp., *Diospyros miokeaki*, *Astronium* (= *Chaneya*) *ninae*, foliage and associated fruits of maples (*Acer palaeoplatanoides* and other species) etc. *Comptonia naumannii* and *Alfaropsis ninae* (former *Engelhardia ninae*) were recovered as single leaf (leaflet) specimens. The presence of the latter, together with a high diversity of the Fagaceae, corroborate a correlation of the Dembi flora with that of the "*Engelhardia* Beds" widely distributed in Southern Primore (Kraskino, Fatashi), Sikote-Aline (Velikaya Kema), Korea and Northern Japan. According to the opinion of the first author (M. Akhm.) the age of the Dembi flora, according to the lack of early Palaeogene elements, still occurring in the flora of Sonye and Bui, and at the same time the appearance of diversified Fagaceae, Betulaceae, Juglandaceae and Aceraceae elements with living analogues, attest to an age of Oligocene to ?Early Miocene. This is also corroborated by radiometric data of the dacitic derivates from the volcano Ozernyi.

Most of the living relatives similar to the fossil species (except oaks with dissected leaves) thrive in mixed mountain forests of East and Southeast Asia, Japan, Central, Eastern and Northeastern China and also in the Korean Peninsula and Southern Primore. They are found in the belt of slope forest, between 200 to 1500 m above sea level, rarely higher. Taking into account the present living conditions of the nearest relatives, the following vegetation groupings can be suggested:

1) Riparian aquatic vegetation, which includes aquatic monocots *Arundo*, *Cyperacites* and also *Hemitrapa*.
2) Riparian vegetation of flooded lake shores with *Taxodium*, *Glyptostrobus*, *Populus*, *Cercidiphyllum* etc.
3) Lower belt of broad-leaved slope forests with evergreen accessory elements. This vegetation type includes most of the woody fossil elements. Leading forest formations are oak forests, apparently pioneer vegetation within active volcanoes. They contain practically all representatives of the Fagaceae, Betulaceae and also most of the warm temperate and subtropical woody plants (*Engelhardia*, *Magnolia*, *Cercis*, *Sapindus*, *Diospyros* and others).
4) Most probably also an independent coniferous-broad-leaved forest existed on the upper belt of slopes, where pines and some broad-leaved trees thrived.

Vegetation units similar to the Dembi type are common in deciduous forests of Central and Eastern China, also in the zones of *Castanea* and *Fagus* of mountain broad-leaved as well as coniferous and broad-leaved forest vegetation in Japan.

Botchi (Miocene)

The site of Botchi (Text-figs 2, 16) is situated in the central part of Eastern Sikhote-Alin', at the south-eastern end of the mountain range dividing the valleys of the rivers Botchi and its southern main tributary Mul'pa. The site crops out ca. 25 km upstream from the village of Grossevichi, on the river Botchi where it empties into the Tatar Strait. Among the local population, the fossil-bearing layer is known under the name of the White Mountain (Belaya gora = in Russian) on account of the blistery colour of outcrops against the darker river valley.

Text-fig. 16. Upper part of the Botchi thin-bedded plant-bearing tuffaceous beds.

The fossiliferous layer, called by the first author (Akhmetiev 1965) the Botchi Formation, has been deposited stepwise over the underlying andesite-basaltoid volcanic body of the Near-shore Volcanic Belt and attains a thickness of 120–150 m. It is overlain by an erosional cover of pebbles and conglomerates with lenses of diatomite clays (Text-fig. 16) – products of accumulations on the cover of the high terrace of the Botchi River. The Pliocene alluvial cover was deposited at 80 m alt. over the bottom of the valley; successively the Pliocene was overlain by Pliocene to (?) Quaternary plateau basaltoids of the Sovgavan' Formation – products of the final volcanic phase of the Near-shore Volcanic Belt. The Botchi Formation falls under an incline of 15–20° towards the south-east. The richest collections of fossil plants were made from the eastern wall of 15 m high cliffs, where the highest layers of the site are exposed.

The Botchi Formation is variable in its content and is comprised of silicified fine bedded devitrificated ashes, tuffites, siltstones, claystones, tuffogenic sandstones and rare lense-shaped flows of andesite-basalts. Towards the base of the section, lava flows with increasing density alternate with clastic deposits and gradually replace them totally. The total thickness of the layer is 50 m. The upper part of the formation, about 100 m thick, includes four fossil-bearing levels. The surrounding rocks contain only rare plant fossils. This part of the outcrop consists of the following rocks (from below):

1) Silicified claystones and thin lenses of light grey and white ashes – 5–20 m thick.
2) Silicified siltstones, bedded, – 2 m thick. This is the 4^{th} fossiliferous layer and contains *Carpinus subcordata*

(mass occurrence), *Alnus protohirsuta* var. *paucinervis* (abundant), *Larix schmidtiana* (single), *Acer* spp. (foliage, fruits) (single), *Tripetaleia almquistii* (solitary), *Sorbus lanceolata* (single) plus additional seed remains of *Pinus*, *Larix* and *Picea*.

3) Silicified siltstones, grey and white, finely bedded – 4 m thick.
4) Diatomites, diatomite clays, leaving traces on hands like blackboard chalk – 2 m tick. This is the 3rd fossiliferous layer and contains *Carpinus subcordata* and *Alnus protohirsuta* var. *paucinervis* (mass occurrence), *Metasequoia occidentalis* (single), *Cercidiphyllum crenatum* (single), *Fraxinus* sp. (single) and *Craigia oregonensis* (frequent).
5) Silicified siltstones, porcelaneous, light grey with characteristic shelly fracture on fresh breakages – 4 m thick. It contains rare impressions of *Carpinus subcordata* and *Alnus protohirsuta* var. *paucinervis*.

6–9) Tuffitic claystones, bedded, as well as massive, silicified interchanging with tuffogenic sandstones (thickness of interbeds 2–4 m) – in total 8.5 m thick.

10) Bedded silicified tuffitic claystones, white and light brown – 3.0 m thick. Rare remains of *Woodsia* and *Abies* (twigs). Common are *Carpinus subcordata* and *Alnus protohirsuta* var. *paucinervis.*
11) Tuffitic sandstones, medium grained, greenish-grey, not compact – 0.8 m in thickness.
12) Silicites (silicified claystones) bedded, light brownish – 3.0 m in thickness. The second fossiliferous horizon includes *Carpinus subcordata* and *Alnus protohirsuta* var. *paucinervis* in masses, *Larix schmidtiana* (frequent), *Picea* (single twigs) and *Muscites* (single).
13) Silicified claystones with addition of ash particles, bedded, light grey and white – 5.0 m in thickness.
14) Diatomite clays, diatomites, devitrificated ashes, white, leaving traces on hands like blackboard chalk – 2.0 m thick. This is the 1st fossiliferous horizon in which *Alnus protohirsuta* var. *paucinervis* predominates, *Carpinus subcordata* is common and other elements occur, such as *Betula* sp. ex sect. *Costatae*, *Carpinus lanceolata*, rarely *Ostrya oregoniana*, *Alnus* spp. (infructescences), *Abies* spp. (twigs, seed cone scales, seeds), *Thuja nipponica* (twigs), *Pinus* sp. and *Picea* sp. (seeds).
15) Tuffogenic siltstones and claystones, light grey, silicified to various degrees – 15.0 m thick.

Occurrences of the Botchi Formation within the Nearshore Volcanic Belt are restricted to grabens and errosional depressions in the area of the town of Sovetskaya Gavan' and southwards from it in the lowlands of the rivers Koppi, Botchi and Mul'pa under the cover of the plateau basalts.

The flora of Botchi has been known since the beginning of the 20th century. Palibin (1904) studied a small collection gathered by Ja. S. Edelshtein. Later collections obtained during geological mapping were studied by M.O. Borsuk and R.Z. Genkina. They both noticed a high species diversity (several tens of species). They arrived at the conclusion (M.O. Borsuk and R.Z. Genkina, personal communication) that the flora is Late Oligocene to Early Miocene in age, although their conclusions have never been published. The Botchi section and its flora were studied in more detailed by L.P. Botyleva, V.D. Ovchininskii and the first author (M. Akhm.) in 1961–62. This new collection includes more than 1000 specimens, which were used for a monographic treatment (Akhmetiev 1965, 1973a, 1988). Later on this collection was complemented by the small collections of A.P. Rasnitsyn and E.K. Sytchevskaya.

Plant remains are represented mostly as leaf impressions, more rarely by seeds and fruits, spread without exception on bedding planes. The maximum quantity of remains was recovered from thinnly bedded silicified brownish tuffites and tuffitic claystones in the floors of ash layers and also from white diatomites and diatomite clays. The deposits containing fossil remains originated in a near shore zone of the lake basin, situated within a circle of volacnic bodies. Some of the volcanoes were active during this deposition.

The Botchi flora (Plate 7, Table 2) includes more than 70 species belonging to 45 genera and 27 families (Akhmetiev 1973a, 1988). The floral content remains in general unchanged within all fossiliferous horizons of the Botchi Formation, although a decrease in frequency of some thermophilous elements can be noticed upwards in the section (*Metasequoia occidentalis*, *Cercidiphyllum crenatum*, *Rhus*, *Phellodendron*, *Acer* and *Nyssa*). On the other hand, the diversity of temperate angiosperms and conifers increases towards the roof of the formation (*Abies*, *Picea*, *Larix*, and *Betula*). The most apparent floral changes take place between the 2nd and 3rd fossiliferous levels and are obviously due to climatic deterioration.

The following vegetation types have been distinguished in the Botchi assemblages:

1) Riparian vegetation at the lake, on periodically flooded lowland adjacent to the lake. This group of plants is represented by *Phragmites*, *Populus balsamoides*, *Rumex*, *Rosa*, various species of *Alnus*, *Phellodendron grandifolium*, *Nyssa* etc.
2) The slope vegetation consisted of plants thriving on low slopes facing the lake. It was comprised of most of the recovered taxa, woody arboreal and shrub angiosperms and also some conifers. Considering the climate of the Botchi period to have been temperate, the plants included in this vegetation type were usually growing higher up on the mountain slopes. On the whole, the slope vegetation sensu lato was composed of Pinaceae, *Metasequoia occidentalis*, *Thuja nipponica*, *Betula palibinii* and other birches, *Pterocarya krishtofovichii*, *Carya* sp., *Carpinus subcordata*, *Alnus protohirsuta* var. *paucinervis*, *Ostrya oregoniana*, most of the representatives of Rosaceae and Aceraceae, *Rhus* sp., *Tripetaleia almquistii*, *Ilex* sp., *Rhamnella elliptica*, *Acanthopanax sichotealinensis*, *Tilia* sp. and *Fraxinus* sp. The shrub understorey consisted of *Alnus*, *Corylus*, *Spirea*, *Crataegus botchiensis*, *Sorbus lanceolata*, *Sorbus morosovae* and *Rubus ovchininskii*. The ground vegetation included *Woodsia*.

The dominating elements of the forest vegetation were *Carpinus subcordata*, *Alnus protohirsuta* var. *paucinervis*, *Metasequoia occidentalis* and various species of *Betula*. Upwards on the slopes, the broad-leaved forests were gradually replaced by conifers (*Abies*, *Larix*, *Picea*, *Pinus*, *Tsuga* and *Thuja*).

The dating of the Botchi flora (the Middle or the beginning of Late Miocene) is based on the assumption that most of its fossil plant elements are closely related to the living species which are thriving at present in broad-leaved and conifer forests in East Asia. The fossil forest vegetation of Botchi can be justly considered as a prototype for the most thermophilous vegetation of contemporary forests of Southern Primore with *Carpinus subcordata* and *Abies holophylla*.

Palaeoecological aspects of the Sikhote-Alin' Cenozoic floras

The Sikhote-Alin' volcanic belt is a heterogenous tectonic structure. From the west it borders the Tatar Strait and the northern part of the Japan Sea. The belt was produced by three phases of volcanic activity: the andesite–rhyolite (Senonian – Palaeocene), andesite-basaltoid (second part of the Eocene – Miocene) and plateau basaltoids (Pliocene). All three volcanic complexes are divided by hiatuses. The age determination is mainly based on palaeobotanical and radiometric data. Plant assemblages were formed at different altitudinal zones (to 1000 m and more above sea level) and in various ecological settings. These circumstances make it difficult to make any correlation between the levels or fossiliferous lenses, even those closely situated geographically and composed of volcanoclastic deposits.

The youngest flora of the andesite–rhyolitic phase, from the end of volcanic activity in the Palaeocene, occurs in tuffogenic lenses. In the southern part of the belt they accumulated in intermountain river valleys and lake lowlands at more than 500 m above sea level (localities in lowlands of the Zerkal'naya and Sobolevka rivers). In the north – in Lower Priamurie (locality Malo-Mikhaylovka), the fossiliferous strata with plant fossils accumulated in swampy piedmont lowland east of the stratovolcano at 200 to 300 m above sea level. In addition to the radiometric dating of the floras as Danian (or Danian – Zelandian), their age estimation is also based on composition and comparison with the type assemblages of the Tsagaian and Kivda Fms (from the strata above the lignite) in the Amur region. The markers in common to these floras are: *Ginkgo* ex gr. *adiantoides, Metasequoia occidentalis, Taxodium tinajorum, Cupressinocladus* sp.*, Trochodendroides arctica, Nyssidium* sp. (large size), *Nyssa bureica, Tiliaephyllum tsagajanicum* and platanoids. Differentiating features of these floras of the volcanic belt are a dominance of conifers and their high diversity, in particular the Pinaceae, a wide spectrum of "amentiferae" mainly *Alnites, Betula* (Sobolevka, Zerkal'naja), *Corylites, Palaeocarpinus* (Malo-Mikhaylovka), *Fagopsis*, Juglandaceae and appearance of taxa closely resembling *Juglans* and *Carya* (Sobolevka). A common element of the Kivda Formation from the Amur region is *Ulmus furcinervis,* which also dominates in the floras of Sobolevka and Zerkal'naya. The floras of the belt appear large-leaved. There are also taxa matching the Rosaceae (*Sorbus, Rubus*) in leaf gross morphology. The sedimentary setting in the Lower Amur depression, where the Malo-Mikhaylovka flora originated, did not remain stable. Lignites and lignite clays with *Muscites, Equisetum, Onoclea, Dennstaedtia, Asplenium* sp.*, Fokieniopsis, Cryptomerites, Amurocyparis, Palaeocarpinus* and *Corylites* accumulated in a periodically swampy basin. Remains of *Ginkgo, Trochodendroides* and *Nyssidium* are usually bound to coarse-grained volcanogenic deposits of river streams which transported the material into the basin from the volcanoes.

The floras of the andesite-basaltoid phase of Eocene to Early Miocene age belong to four stratigraphical levels.

The floras of the first level occur in tuffogenic-clastic lenses that originated in erosional depressions of the prebasaltic palaeorelief (floras of the Sonje Bay, Svetlovodnaya). In these floras the following relicts survive: *Trochodendroides,* various platanoids, *Fagopsis* and *Plafkeria.* The spectrum of gymnosperms is exceptionally diverse: *Ginkgo, Taxus, Podocarpus, Pinus, Cryptomeria, Metasequoia, Taxodium, Cunninghamia, Sciadopitys, Thuja* and *Thujopsis.* At the same time the genera characteristic of the Oligocene and Miocene appear: *Alnus, Carpinus, Fagus,* and *Quercus* with dissected leaves, *Vitis, Tilia* and *Acer*. New elements previously unknown in Asia were found (*Deviacer*). The age of these floras is Late Eocene.

The floras of the second level occur in tuffs and tuffogenic sandstones bound to the lower part of the andesite-basaltoid complex (localities Bui, Siziman, Sjurkum). Their age is Late Eocene or Oligocene. They have been usually found in thinner lenses of the lake facies (Bui) and include Cupressaceae, *Cercidiphyllum, Macaranga, Palaeocarpinus, Fagopsis, Plafkeria, Craigia* and *Acer.* In other cases, fossil plants were fossilized in ashes in their original living position (Siziman) or were only transported short distances from the volcanic centres. They accumulated in small depressions of the relief (Sjurkum). These plant assemblages reflect vegetation of the slopes. Many of them are extraordinary and so far not clarified taxonomically. In the Siziman flora *Metasequoia* dominates*,* in addition, ferns occur (*Dryopteris, Onoclea)*, *Larix,* various Betulaceae and Ulmaceae. Among lianas are Leguminosae (*Wistaria, Pueraria*). In the Sjurkum flora the main part consists of leaves of *Myrica, Salix, Alnaster, Rhododenron* and *Vaccinium.* These plants thrived at higher altitudes above sea level.

The flora of the third level, also Oligocene in age, is known from the site of Amgu. Plant remains there also reflected slope vegetation. Foliage of large to medium size prevails and mostly belongs to shrubs. The main part of the assemblage (more than 70%) consists of the remains of conifers (*Ginkgo, Podocarpus, Abies, Picea, Pinus, Pseudolarix, Tsuga, Glyptostrobus, Metasequoia* and Cupressaceae*).* The representation of "Amentiferae" and Ulmaceae is much lower. More diversified are Rosaceae (*Cerasus, Pyrus, Prunus, Sorbus* and *Spiraea*) and *Acer.* The flora of Sjurkum and also that of Amgu, is cool temperate.

The flora of the fourth level corresponds to the final phase of the andesite-basaltoid complex (final Oligocene to Early Miocene). In small lake depressions between volcanic bodies accumulated diatomites and also plant remains. The typical floras are known at the sites Dembi and Velikaya Kema. According to the high frequencies of Taxodiaceae, Fagaceae (*Fagopsis, Quercus, Castanea, Castanopsis*), Aceraceae and the occurrence of *Comptonia, Ailanthus, Eucommia, Cercidiphyllum, Craigia, Rhus* and *Engelhardia,* these plant-bearing beds are near in age to the "*Engelhardia*" beds of Southern Primore and Northern

Korea. Leaves of Lauraceae and Magnoliaceae testify to their almost subtropical character. The flora of Velikaya Kema differs by small size of foliage and also fruits (*Craigia*). The flora of Dembi consists of several ecologically different components – lowland forests and periodically flooded habitats (*Taxodium, Glyptostrobus, Populus*) and populations of the lower part of the broad-leaved slope forests, where the Fagaceae dominated. This part of the assemblage may represent pioneer vegetation within the active volcanic area. It is most probable that also independent higher slope vegetation existed where Pinaceae, some Betulaceae and shrubs thrived.

The youngest plant-bearing levels of the Miocene accumulated after the formation of the andesite-basaltoid complex in individual troughs and erosional depressions of the newly originating hydrological network facing the shore of the Japan Sea. These accumulations were later buried by Pliocene plateau basalts. The richest of the sites is the flora of Botchi from lake claystones (gaizes) and diatomites. It consists of more than 70 taxa and reflects various ecological settings of slope vegetation. It is distinguished by a wealth of conifers, particularly Pinaceae, in addition to Betulaceae (*Betula*, *Alnus*, *Carpinus*), Aceraceae, Tiliaceae (*Craigia*), Rhamnaceae, Oleaceae and Caprifoliaceae. The nearest living relatives of the Botchi flora thrive mainly in the upland forests of Southern Primore, northern Japan and the Korean Peninsula. The fossil forest vegetation of Botchi may be considered as a direct ancestor of modern forests with *Abies holophylla* Maxim. and *Carpinus cordata* Bl. of Southern Primorie.

Central Europe – Bohemian Massif and adjacent areas

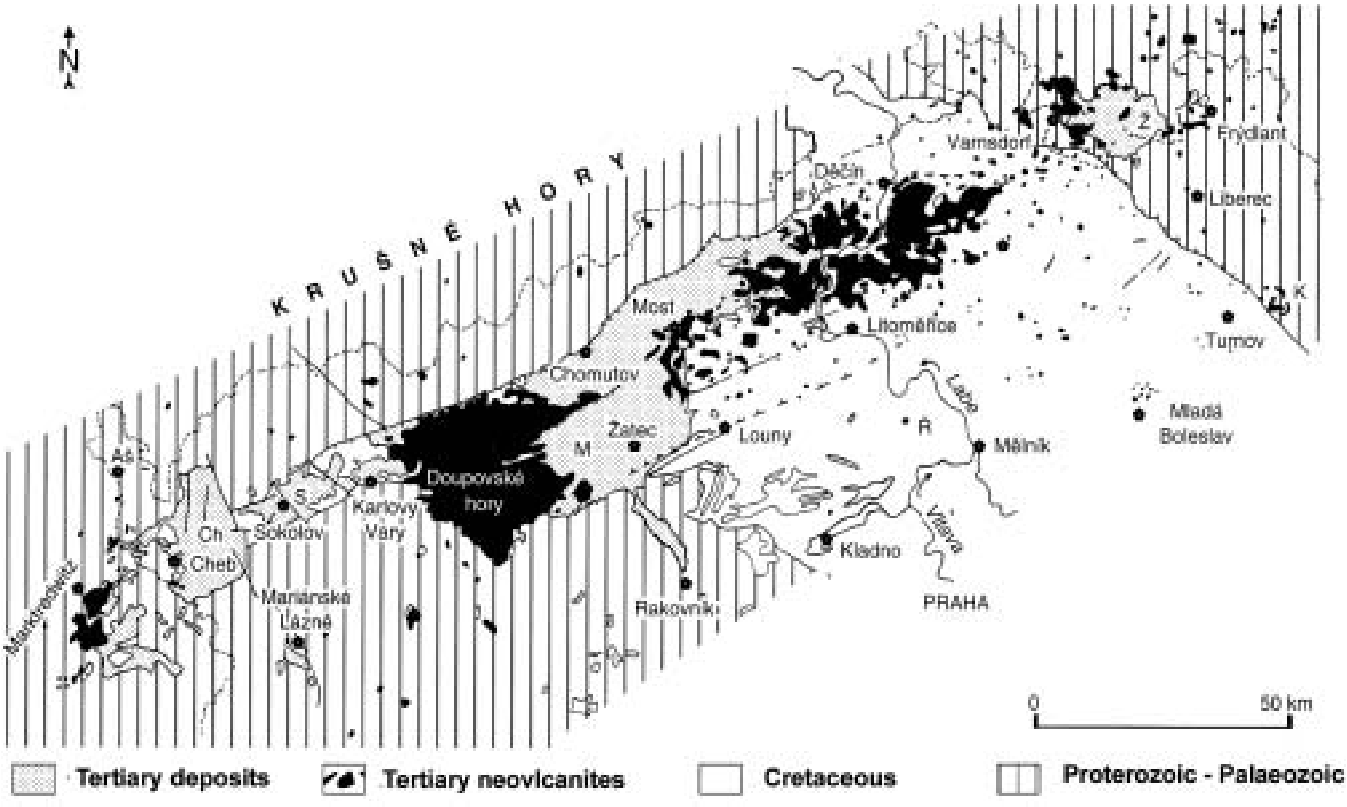
Cenozoic volcanism and its flora in the České středohoří Mountains volcanic centre and its periphery

(Z. Kvaček, H. Walther)

Several large areas of neovolcanism arose during the Palaeogene in Central Europe. One of the best known since very beginning of geological explorations (dispute between neptunists and plutonists at the beginning of the 19th century) occurs in the Bohemian Massif. According to the latest interpretation (see Ulrych et al. 1998) an extensive rift system originated in western and Central Europe as a product of the collision of the African and Eurasian plates in the Early Cenozoic and displays tectonic activity continuing until the present. This system which had an input on the Variscan horst blocks extended from the Massif Central (France) via the Rhenish Massif (Germany) to the Bohemian Massif (Ziegler 1982). The magmatic masses of this system evolved as a reaction of the Variscan foreland to later phases of the Alpine orogeny (Sengor 1976). Volcanic activity may have arisen due to lithospheric flexures that caused displacement of large parts of the lithosphere resulting in mantle upwelling followed by adiabatic decompression, melting processes in the upper mantle and injection of magmas. A different concept proposes the presence of several mantle plumes or a single large hot spot.

The volcanism of the Bohemian Massif is an important part of the Central European Volcanic Province (Wimmenauer 1974) and is genetically and spatially associated with the taphrogenic structures of the Bohemian Massif. The origin and distribution of volcanism there are, according to Kopecký (1978), controlled by the above mentioned structure explained as a rift known as the Ohře or Eger Rift, running along the Labe (Elbe) tectonic-volcanic zone in a NNW-SSE direction (Text-fig. 17). The structure can be followed from the Upper Palatinate (Germany) across the Doupovské hory Mountains, the České středohoří Mountains to the Lusatia Mountains in northern Bohemia and terminates in the Zittau (Žitava) Basin at the German – Bohemian – Poland frontier. According to the K/Ar radiometric dating, various magmatic bodies and associated sedimentary/pyroclastic rocks arose in the time interval between the Late Cretaceous and the Quaternary. Ulrych and Pivec (1997) recognized a pre-rifting series of unimodal ultramafic ultraalkaline volcanism bound to external blocks, which can be dated to 79 to 51 Ma. The main part of the rift belongs to the rift series of alkaline character. Generally, three phases of the rift series have been recognized: contemporary bimodal (basanite-trachyte and olivine nephelinite-phonolite) and mostly unimodal (foidite) rock series lasting between 42 to 16 Ma, coexisting unimodal (foidite) and strongly, as well as weakly, alkaline series 12 to 8 Ma old and the youngest unimodal (foidite) series developed only in western Bohemia and northern Moravia 4.6 to 0.26 Ma old.

The major volcanic centers are interconnected via brown coal basins wedged between them throughout the Eger Rift. This situation in particular allows the study of facial transitions between basin and magmatic strata and plant assemblages connected with them. Thus the Sokolov Basin and the Doupovské hory Mountains form a twin geological unit where the undivided Doupov volcanic complex splits into several formations recognized within the Sokolov Basin (Rojík 2004). The earliest unit that can be traced from the Cheb (Eger) Basin on the extreme west towards the České středohoří Mountains is the river deposit of the Staré Sedlo Formation, late Eocene in age. This river continued along the rift structure into the NNW and connected the Eger Rift with the Weisselster Basin in Saxony. The river obviously supplied lakes of the Doupov volcanic complex and stretched eastwards to the České středohoří Mountains. In the Doupovské hory Mountains, the Late Eocene lake deposits are represented by massive limestone which yielded a florula with *Doliostrobus* and evergreen dicots occurring at the very base at Valeč (Bůžek et al. 1990). Most of the overlying volcano-sedimentary part of the complex belongs to the Oligocene – Early Miocene. The present treatment does not focus on this area, which requires more palaeobotanical research, but may nicely exemplify how two facially different units, an extensive brown-coal basin and a complex of volcanoes, may offer a good opportunity to follow vegetation changes due to basinal vs. volcanic environments. The coal-forming Early Oligocene vegetation in the Sokolov Basin was dominated by marshland ferns of *Pronephrium, Eotrigonobalanus* and



Text-fig. 17. Ohře (Eger) rift in Central Europe with main magmatic structures (from Cajz et al. 1999, adapted).

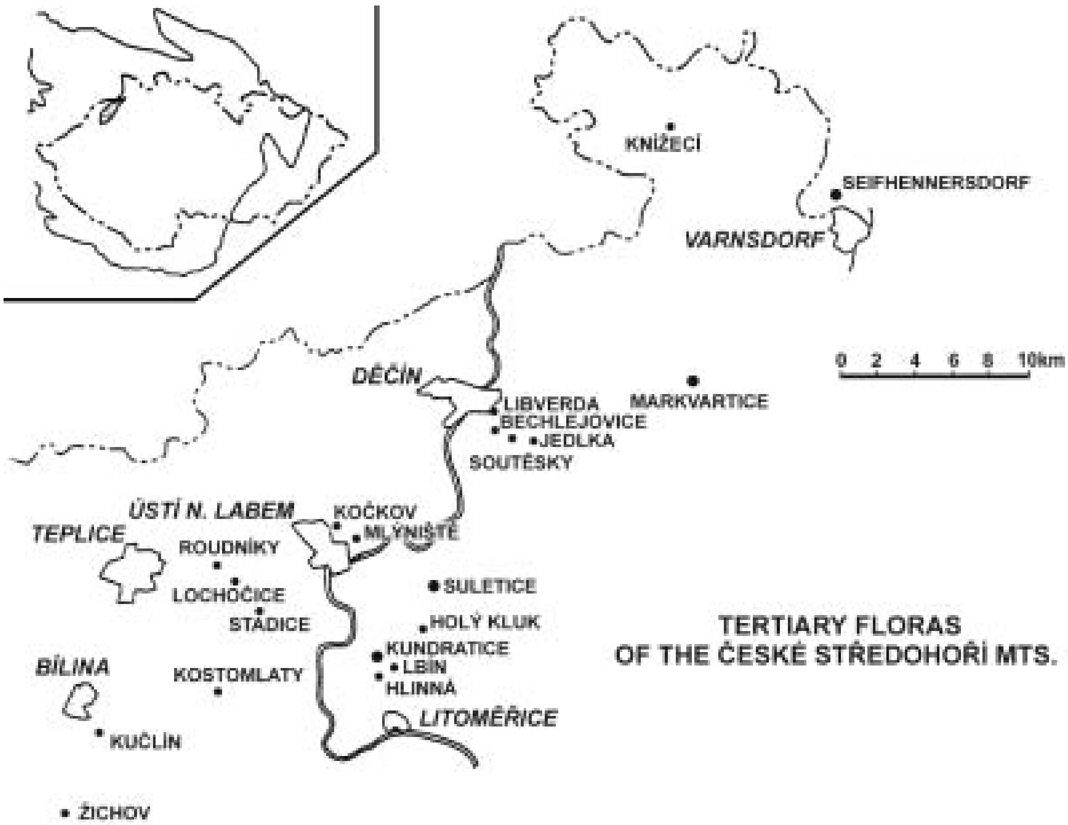
Taxodiaceae found in the lower part of the basin fill while towards the Doupov volcanic complex it was replaced by more mesophytic vegetation consisting of *Pinus*, Lauraceae, *Platanus neptuni*, *Mahonia*, *Smilax* and other woody elements in the volcanic strata, e.g. at Dvérce and elsewhere nearby (Bůžek et al. 1990, Kvaček and Teodoridis 2007).

Within and on the periphery of the Ohře (Eger) Rift there also arose several maar lakes differing in age. The age differences of the included plant assemblages are reflected more in the floral composition rather than vegetation and environmental setting which largely remained similar (Walther 1998, 1999 and the next section below).

The České středohoří Mountains, situated in the central part of the rift structure, represent the largest magmatic complex explored in detail (for review see Ulrych et al. 1998, Cajz 2000). A more detailed treatment of this area including its floras (Text-fig. 18) is offered here as a summary of palaeobotanical research carried out there since 19th century.

According to previous petrological and geological explorations, a newly developed interpretation of this traditional unit of the northern part of the Bohemian Massif has been formulated (Ulrych et al. 1998, Cajz 2000). The České středohoří volcano-sedimentary complex is the most complicated within the Eger Rift. It is a polygenetic assemblage of Cenozoic alkaline superficial and intrusive volcanism, pyroclastics and accompanying sedimentary intercalations. It forms a 20 to 25 km wide and 80 to 90 km long mountain range composed of an almost uninterrupted series of volcanic products, which are also scattered in the wider surroundings over the Bohemian Massif and usually referred to this unit. This is also the type area of the Atlantic Province sensu Becke (1903) and the Atlantic Suite sensu Harker (1909). Shrbený (1995) estimated the volume of the preserved volcanic products at 52 cubic km. About 40% of volcanic products are volcanoclastic and volcano-sedimentary rocks.

Cajz (2000) attempted a formal division of the complex into several formations. His lithostratigraphic system is based on genetic differentiation of magma and supported by radiometric ages (K-Ar age determinations) of volcanic bodies (e.g. Bellon et al. 1998). Kvaček and Walther (2001) added a new subdivision of the complex into several informal levels according to the floral and vertebrate faunal changes. Complications of dating arose due to subaerial versus intrusion bodies and their succession in the profiles. The subaerial lava flows indicate minimal age for the deposits below. Intrusions are always more or less younger than the adjacent deposits and cannot be employed for exact dating of the whole series. Striking examples were published by Bellon et al. (1998) leading to false dating of Bechlejovice, Suletice and Lbín by radiometric age of much younger intrusions. The following review will characterize the suggested levels more accurately, assuming the above mentioned misleading absolute ages, with references to more recent accounts on floristic characteristics (Kvaček and Walther 1995, 1998, 2004, Radoň et al. 2006, Walther and Kvaček 2007). Also extensive new documentation of recent collections so far only partly published (Bellon et al. 1998, Kvaček 2002, Kvaček and Teodoridis 2007) is included.



Text-fig. 18. Geographical position of the main palaeobotanical localities in the České středohoří Mountains.

Kučlín (Late Eocene)

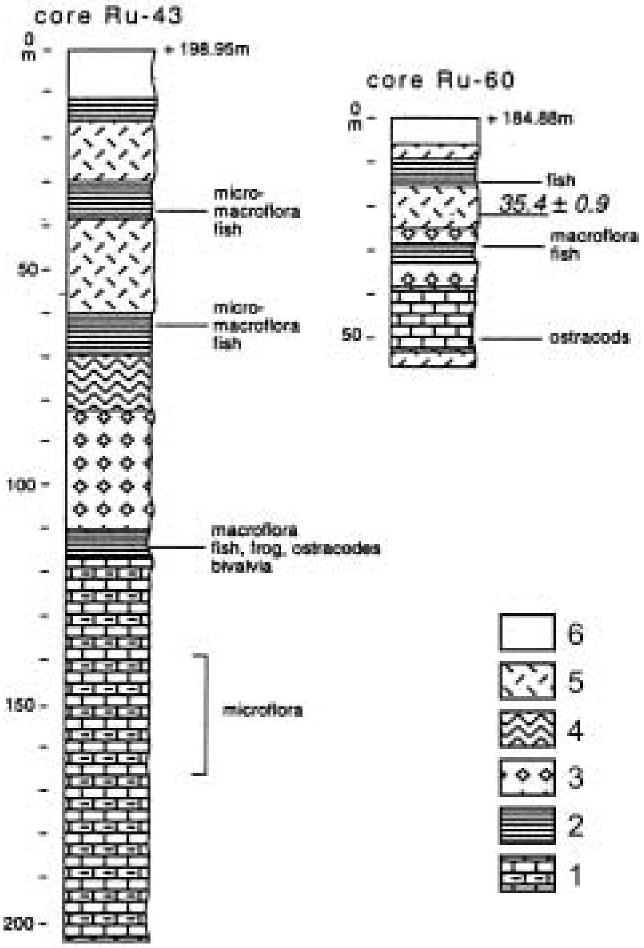
The very base of the complex is formed by the fluvial deposit of Late Eocene age mentioned in the introductory section, called the Staré Sedlo Formation which is mostly transformed into firm quartzite in the České středohoří area (Žitenice, Skalice). The flora occurring at several sites near Litoměřice includes several markers, e.g. *Steinhauera* and *"Sterculia" labrusca* (Knobloch et al. 1996) and the assemblages are uniform, reflecting azonal riparian vegetation dominated by an extinct Fagaceae *Eotrigonobalanus* together with the Lauraceae of the *Daphnogene* type, palms and ferns. The contemporaneous Eocene volcanic development of this region started by degassing of the magma chamber along the deep-seated tectonic structures. Phenomena of this phase – maars and diatremes – are preserved along the SE margin of the volcanic range. The intravolcanic sedimentation of limestone, marl, coal seams, fine-grained tuffite and diatomite type formed a belt on the SE periphery of the mountain range which starts near Kučlín (Trupelník, formerly Trippelberg Hill) and continues to Kostomlaty, Lbín and Hlinná reaching towards Litoměřice (Kudratice, core Ku 1), the bottom of the volanic complex. Kvaček (2002) recognized the existence of a large freshwater lake between Bílina and Litoměřice at this time, which was later inundated by waters of the river system. This idea was put forward by Böhme (Micklich and Böhme 1997) who recovered a marine fish, *Morone*, in the fish fauna of Kučlín which might have penetrated there from the ancient North Sea via the river system in Saxony and North Bohemia. An ancient freshwater fish fauna with *Amia/Cyclurus – Thaumaturus – Properca/Bilinia* typifies this level (Böhme 2007). The flora of Kučlín (Plate 8, see also Ettingshausen 1866–69, Kvaček 2002) is markedly different from the riparian plant assemblages of the Staré Sedlo Formation (Table 3), although common elements do occur (*Eotrigonobalanus, Daphnogene*, *Sabal*). Ancient elements, such as *Acrostichum* and *Rumohra* among ferns, *Doliostrobus* among conifers and several angiosperms (*"Ficus"daphnogenes, Cedrelospermum lineatum*) connect the assemblage with the Middle Eocene floras of Germany, namely of the Messel and Eckfeld maars. The late Eocene character is stressed by a rich occurrence of *Platanus neptuni, Engelhardia orsbergensis & E. macroptera* and *Sloanea nimrodi* which started to appear in Saxony in the Late Eocene Zeitz floral assemblage (Mai and Walther 1985). More links can be also found to the Early Oligocene floras of the Bembridge marls (England), Tard Clay (Hungary) and Socka (Slovenia), e.g. *Doliostrobus, Ziziphus ziziphoides, Raskya, "Acer"sotzkianum, "Sterculia" labrusca.* Although a more precise assessment of the palaeoclimatic conditions of the Kučlín level is so far not available, a mere floristic comparison leads us to assume an almost sub-humid subtropical regime, in which only purely azonal elements (Nymphaeaceae, *Eotrigonobalanus*, *Sabal*) produced larger-sized foliage. The main body of the assemblage is composed of thermophilous, but mostly deciduous plants (*Platanus neptuni, Engelhardia* sect*. Palaeocarya, Cedrelospermum* and *Sloanea*) while Lauraceae except *Daphnogene* are scarcely represented. Noteworthy are *Pungiphyllum*, *Hydrangea*, *Ailanhus* and *Hooleya.* The contemporaneous assemblage of Kostomlaty includes *Ulmus*-like and *"Ficus"reussii* leaf remains and belongs to the same level, which is also corroborated by fish fauna (Böhme 2007). The modern Arcto-Tertiary element is almost lacking (Kvaček 2002). The dating of the Kučlín level derives from a sample of tephrite assigned to an age of 38.3 Ma by K-Ar age determination (Bellon et al. 1998). The character of the flora still reflects the pre-Grande Coupure thermal regime before the sudden cooling event at the Eocene/Oligocene boundary.

Roudníky (Late Eocene)

The lower unit of the České středohoří complex, called the Ústí Formation (Cajz 2000), consists of products of olivine-rich basaltic volcanism and represents the largest volume of magmatic rocks in this area. In age it ranges, according to the K-Ar dating, between 36.1 to 25.5 Ma (Cajz et al. 1999). These rocks are mostly effusive basanitic lava flows, partly altered and brecciated, or fossil-weathered. Associated volcaniclastics range from coarse-grained to fine-grained types, but their origin is not only pyroclastic. Sandy and clayey intercalations of different age, together with bituminous shale, diatomite, coal and limestone are common and mostly fossiliferous.

The Ústí Formation contains the oldest flora of the Arctotertiary type in the České středohoří Mountains after the Grand Coupure typified by the assemblage at Roudníky (Bellon et al.1998) and dated to 35.4±0.9 Ma (Text-fig. 19, Plate 9). The sites are bound to intrabasaltoid pellitic to coarse-grained pyroclastics between lava flows on the edge of the coal-bearing Miocene near Ústí nad Labem (cores at Modlany, Roudníky, outcrops in the former coal mine Antonín Zápotocký at Chabařovice). The fish fauna contains an indication of *Ammia*/*Cyclurus* and Umbrids (Gaudant in Bellon et al. 1998). The flora (Table 4) is almost purely Arcto-Tertiary, dominated by a deciduous broad-leaved component, e.g. *Liriodendron*, *Ostrya*, *Alnus gaudinii*, various maples, Rosaceae, Ulmaceae and only a few surviving thermophilic Lauraceae, *Mimosites* and *Platanus neptuni* (Bůžek and Kvaček in Bellon et al. 1998). New collections (at Headquaters of Bílina Mines – DB) added new genera, *Juniperus* and *Torreya* among the conifers and further post-Grande Coupure immigrants – *Craigia*/*Dombeyopsis*, *Carpinus mediomontana*, *Nyssa* and *Rosa* fruits, *Leguminosites*, *Cyclocarya* and *Cercidiphyllum* (twigs with brachyblasts, fruits, seeds and foliage).

The floras of the Kučlín and Roudníky levels are striking different, although only a 2 million year age difference. We must predict a severe cooling event occurred between them.



Text-fig. 19. Geological position of the flora of Roudníky in the cores Ru 43 and Ru 60 and radiometric dating (from Bellon et al. 1998, adapted). 1 – xenolites intercalated with claystone, 2 – claystone, 3 – pyroclastite, 4 – tuffaceous claystone, 5 – olivine basalt, 6 – Quaternary cover.

Bechlejovice (Early Oligocene)

The well known site of fossil frogs (Špinar 1972) at (now within) the town of Děčín (Text-fig. 18), called Bechlejovice (formerly Bachelsdorf) also belongs to one of the oldest sections within the Ústí Formation. The section consists of a more than 50m thick sequence of volcaniclastics and pyroclastics including thin seams of coal and also thicker banded diatomite layers rich in plant and amphibian fossils (Kvaček and Walther 2001). A younger age was previously wrongly attributed to it, relying on dating of much younger tephrite intrusions (Bellon et al. 1998). The fish fauna includes only *Umbra* consistent with the Roudníky assemblage. The flora has much in common with Roudníky. The plant assemblage is much more diversified, consisting of more than 70 plant elements. The macrofossil assemblage (Plate 10) also reflects almost purely deciduous forests surrounding the diatomite lake. It includes, in addition to a few ferns (*Polypodium* common to Roudníky, *Rumohra* common to Kučlín) and a single conifer, *Torreya,* an array of broad-leaved woody angiosperms, of which most are shared with Roudníky (*Ostrya* and other Betulaceae, maples, legumes, Ulmaceae, Rosaceae with fruiting *Rosa*, *Craigia, Cercidiphyllum, Pungiphyllum* and *Ailanthus*). Some are of still more ancient origin (*Platanus schimperi* from the French Palaeocene, *Sterculia crassinervia*, *Ziziphus* shared with Kučlín and the Early Palaeogene *Haemanthophyllum*), but some angiosperms newly appeared, namely *Cornus, Ampelopsis, Populus zaddachii, Tilia gigantea, Comptonia*, *Toxicodendron*, *Smilax* and *Diospyros* which connect the Bechlejovice flora with younger levels of Kundratice – Seifhennersdorf (Table 4). The palaeoclimatic data (according to A. Bruch and V. Teodoridis in Kvaček and Walther 2004) indicate a Mean Annual Temperature of about 15–16 °C and the mean temperature of the coldest month ca. 10 °C under conditions of a humid climate (mean annual precipitation slightly over 1000 mm).

Kundratice (Early Oligocene)

The next level situated in the olivine-rich basaltoid Ústí Formation falls within the age of ca. 32 Ma, when a warming trend started and a new fish fauna including *Gobius/Pirskenius* and *Protothymalus/Varhostychtis* immigrated there (Kvaček and Walther 2003, Böhme 2007). A series of palaeobotanical sites belong to it, namely Kundratice, Seifhennersdorf and the Hrazený Hill (former Pirskenberg) at Knížecí. Most of them represent fills of small volcanic lakes scattered over the northern part of the České středohoří Mountains and adjacent Lusatia.

The first flora of this level (Text-fig. 18) was described as early as 1885 by Engelhardt from the "Jesuitengraben" of Kundratice (Engelhardt 1885) and revised by Kvaček and Walther (1998). The volcanoclastic part of the section at Kundratice is more than 200 m thick and is covered by sheets of olivine-rich basanite, the oldest one dated to 32±0.82 Ma (Bellon et al. 1998). The environs of the site are built of nepheline basanite sheets with enormous autoclastic, autometamorphozed volcanoclatic layers that arose in an aquatic environment (Cajz 1992). Two fossiliferous diatomite seams have been penetrated by the core KU 1 that revealed the complete section (Kvaček and Walther 1998). The deeper layer belongs to the more ancient Late Eocene part of the volcanic complex and contains an ancient fish fauna including *Properca/Bilinia* (Obrhelová 1976, Böhme 2007) and a florula which may correspond to the Kučlín level (Kvaček 2002). The Kundratice flora itself has been collected from an outcrop in the Jesuit Valley ("Jesuitengraben") and corresponds to the upper diatomite seam and bituminous shale containing a different fish assemblage with *Protothymalus /Varhostychtis* (Bellon et al. 1998). After revision, the flora (Table 4) now contains 2 ferns, 4 conifers and 82 angiosperms. *Osmunda lignitum* and *Pronephrium stiriacum* are wide spread in the Early Oligocene floras elsewhere in Europe. Among conifers, *Tetraclinis salicornioides* and *Torreya bilinica* survived from the previous older levels, and two new species appeared for the first time: *Cephalotaxus parvifolia* and *Taxus engelhardtii.* Many angiosperms, particularly maples, Ulmaceae, Tiliceae, Juglandaceae, Rosaceae, Leguminosae, *Toxicodendron*, *Ailanthus* and many others continued from the Bechlejovice assemblage. However, the proportion of the Palaeo(sub) tropic/evergreen elements (5 Lauraceae, *Ilex castellii, Sloanea artocarpites, Magnolia* and *Engelhardia*) increased giving the Kundratice assemblage a Mixed Mesophytic Forest character (Kvaček and Walther 1998). The percentage of entire-margined woody angiosperms amounts to 37%, which allows the expectation of some warming trend, in contrast to the Roudníky/Bechlejovice level.

Seifhennersdorf – Varnsdorf (Early Oligocene)

The recently reviewed flora of Seihennersdorf is situated on the German side of the border of Bohemia and Saxony (Text-fig. 18) and an adjacent small remnant of the same deposit at Varnsdorf in the Czech Republic yielded a florula similar in composition (Walther and Kvaček 2007). This level represents another plant assemblage of the same age as Kundratice. It consists of almost the same plant spectrum, enriched by azonal riparian forest elements such as *Taxodium*, *Eotrigonobalanus, Salix, Nyssa* and various aquatic herbs (*Dusambeya, Spirematospermum, Leersia, Potamogeton*). The site is geological well explored (Ahrens 1957) and the section revealed by the core Seifhennersdorf 1/54. It contains five fossiliferous seams of laminated diatomite deposited amid variously grained pyroclastic and tuffitic layers and covered by sheets of olivine-rich basalt, radiometrically dated to 30.2 ± 1.5 Ma and 30.7 ±0.7 Ma (Bellon et al. 1998). The core starts with granite arkose and fine-grained tuff, which level up the basis of the lowermost 5th diatomite seam that originated in near-shore environment and yielded mostly the above mentioned azonal vegetation, frogs and tadpole fossils. The next level upwards, the 4th diatomite seam, is the main source of fossils including a typical fish fauna of *Gobius/Pirskenius* and *Protothymalus/Varhostychtis* (fauna b in the sense of Obrhelová and Obrhel 1987, Böhme 2007). A transitional zone of interchanging tuffaceous and diatomite beds is wedged between these diatomite seams and overlain by 14 m of coarse- to fine-grained pyroclastics, barren of fossils. Due to the reduction of the water body during volcanic events, the 3rd and 2nd diatomite seams contained within the pyroclastics, are very thin and without fossils. Intensive volcanic activity led to the accumulation of massive, several meters thick, non-bedded tuff and was interrupted only briefly, when the 1st diatomite seam and an above laying thin bituminous coal layer arose. According to Walther (1964), this uppermost diatomite was probably the source of the fossils described by Engelhardt (1870) in his first contribution to the flora of Seifhennersdorf.

According to the latest revision of the flora (Plate 11), the megafossil plant spectrum (Table 5) consists of three ferns (two shared with Kundratice and the additional *Salvinia*), five conifers (three shared with Kundratice and the additional azonal *Taxodium* and *Quasisequoia*) and more than 80 angiosperms. Only a few woody angiosperms have been added to the spectrum listed for the Kundratice flora, mainly *Laurophyllum meuselii*, *Magnolia seifhennersdorfensis* and *Saportaspermum dieteri*. Based on carpological records, additional genera and species have been documented, e.g. *Carya* cf. *quadrangula*, *Prunus*, *Nyssa*, *Schefflera*, noteworthy is the occurrence of the rare *Quercus lonchitis*, *Celtis pirskenbergensis, Palaeohosiea* and *Oleinites,* unknown at Kudratice. Palaeoclimatic reconstructions derived from the Seifhennersdorf flora are based on the Co-existence methodology (Uhl in Walther and Kvaček 2007) and indicate the mean annual temperature to have been 15.6 to 15.9 °C, the mean temperature of the coldest month to have been 5.0 to 5.2°C and the mean annual precipitation to have been 897 to 971 mm.

Suletice and Holý Kluk Hill (Early Oligocene)

The floras of Suletice and Holý Kluk Hill at Proboštov (Bůžek et al. 1976, Kvaček and Walther 1995, Radoň et al. 2006), which are included in this level, indicate the peak of warming trends in the late Early Oligocene. Their stratigraphical position is equivocal. All are seemingly connected with the trachybasaltic volcanism, ranged by Cajz (2000) into his Děčín Formation, but the fossiliferous layers are embedded into basaltoid pyroclastics of the Ústí Formation. None of the listed sites yielded ichthyofauna.

In the wider surroundings of Velké Březno, Proboštov and Suletice east of Ústí nad Labem (Text-fig. 18), a depression filled with sedimentary rocks, diatomite layers and coal seams arose in and after the period of the olivine-rich basaltoid volcanism. The geological structure at Suletice is complicated by tectonics and land slides and not well clarified in spite of various cores (Gabriel in Kvaček and Walther 1995). The fossil flora (Table 4, Plate 14) is bound to diatomite layers and dark pellitic tuffite lenses scattered within the re-transported pyroclastics. Because of the identical composition of fossil plant spectra, deposits of similar composition near the Holý Kluk Hill (Radoň et al. 2006) are correlated with that at Suletice. Also there, coarse grained pyroclastics interchange with fossil-bearing claystone to clayey diatomite and fragmented coal seams. These fossil-bearing strata at Holý Kluk are covered by a shallow intrusion of trachybasaltoid that forms the hill and is dated by K-Ar method to 30.9±1.5 Ma (Balogh in Radoň et al. 2006). In this respect the dating of Suletice to 19±0.5 Ma (Bellon et al. 1998) appears misleading because the samples of the magmatic rock analysed derive from a surface sample much younger than the site itself.

The fossil floras in both areas are typified by the occurrence of a new conifer, *Calocedrus suleticensis* (Kvaček 1999). In addition, ferns (*Rumohra*, *Polypodium* – Kvaček 2001), conifers (*Tetraclinis*, *Cephalotaxus* and *Torreya*) and angiosperms, both deciduous and evergreen, survived from the previous levels. The angiosperm spectra are quantitatively dominated by two thermophilic elements, *Sloanea* and *Engelhardia* (*Palaeocarya*), which form the core of the assemblage. The thermophilic character is also stressed by the occurrence of *Palaeohosiea* (Kvaček and Bůžek 1995) and *Oleinites.* Considering the qualitative composition of both the plant assemblages, there is little difference from the previous level and the domination of thermophilic components is only due to taphnonomic process (expression of local conditions) so common within volcanic floras. The forests surrounding the diatomite lake of the Suletice – Holý Kluk area obviously formed dense stands on elevated shores, close to the place of deposition. The re-appearance of plants typical of the Kučlín level, namely *"Acer" sotzkianum*, *Palaeohosiea* and *Sloanea* in the Holý Kluk assemblage is important considering climatic changes.

The plant assemblage of Markvartice (Text-fig. 18) which is dominated by *Platanus neptuni, Sloanea* and diversified Lauraceae (Table 4, Bůžek et al. 1976), is noteworthy for the occurrence of sabaloid palms which should correspond, due to its thermophilic character, to those of Suletice and Holý Kluk Hill and obviously belongs to the same level. It differs by the scarcity of *Engelhardia* and the lack of *Palaeohosiea*. The diatomite and bituminous shale at Markvartice and nearby Veselíčko (formerly Freundensheim) are well known for fossil frogs. The fossil-bearing layers were exposed by short-term coal mining from 1858 to 1859 and newly struck by the core CK 2. Oberhelová (1969) recorded the ichthyofauna containing *Varhostichtys* (i.e. *Protothymalus*), and newly added *Palaeorutilus* cf. *papyraceus* (Böhme 2007). The flora includes more than 60 elements of higher plants. No radiometric data are available from the tephritic body covering the fossiliferous strata there. Kvaček and Walther (2001) assigned the levels of Suletice and other sites treated, above to the late Rupelian climatic optimum (Floral Assemblage Nerchau-Flörsheim). Considering the occurrence of *Palaeorutilus* cf. *Papyraceus,* a correlation with the Late Oligocene shale of Rott may also be considered.

Matrý – Žichov (Late Oligocene)

The next unit of the České středohoří complex was defined by Cajz (2000) as the Děčín Formation (30.8 to 24.7 Ma). He visualized the Děčín Formation as formerly a large composite volcano (stratovolcano), now represented by relics in several smaller areas. These relics are composed of mostly re-transported pyroclastics, intercalated with thin trachybasaltic lava flows. Local breccias indicate a subaerial origin of the effusions. The lavas constitute a minority of the volcanic products while clastic material prevails. Lapilli and ash-grained material are re-deposited with admixed clasts coming from destructed lavas.

The site on the Matrý Hill (Text-fig. 18) was recovered by Radoň and belongs to the Děčín Formation (Cajz 2000). The fossiliferous layer crops out within the trachybasaltic pyroclastics on the slope of the Matrý Hill, NE of Sebuzín (Radoň 2001). It consists of interchanging grey, fine-grained tuffite and thinly bedded yellowish diatomite. The top of the hill is formed by younger olivine-rich lava flows of the Dobrná Formation (24.0 to 19.3 Ma – Cajz 2000) that originated due to rejuvenation of volcanic activity. Radiometric dating of the fossil-bearing strata belonging to the Děčín Formation is not available so far.

The flora (Table 4, Plate 12) is dominated by deciduous broad-leaved trees, belonging mainly to Betulaceae, Ulmaceae, *Liriodendron, Acer* spp. with minor additions of more thermophilous plants, such as *Platanus neptuni, Sloanea nimrodi* and Lauraceae. Four conifers (*Calocedrus*, *Tetraclinis*, *Cephalotaxus* and *Torreya*) survived from the previous levels. A noteworthy modernization of the flora is stressed by new immigrants, typical and widely spread in North Bohemia in the Early Miocene deposits of the adjacent North-Bohemian brown coal basin, namely *Woodwardia muensteriana, Pinus rigios, Pinus hepios* and *Ulmus pyramidalis.* In contrast to the Suletice level, a reduction of termophilous elements (*Engelhardia*, *Palaeohosiea*, *Mimosites*) attests to cooling trends in the Late Oligocene.

The same aspects and almost the same composition to the Matrý Hill flora can be found in the classical site of Žichov (Schichov) (Text-fig. 18, Table 7, Plate 13) described by Ettingshausen (1866–1869). In this case, fossils are embedded in the freshwater limestone and silicified diatomite transferred into the sediment resembling opal, which occurred previously at the bottom of the Lužice creek valley. Higher up above the fossiliferous layer, basaltoid breccia and a lava flow cropped out (Reuss 1840). The southern boundary of the site is built of lava flows of the leucitic- nepheline basanite. Radiometric dating is not available. The site yielded various vertebrates, notably frogs, salamander and a new ichthyofauna dominated by *Palaeorutilus medius* (i.e. *Leuciscus* (*Palaeoleuciscus*) *luzicensis* sensu Obrhelová 1969, 1979) and is ranged into the Late Oligocene (Böhme 2007). The site is the type locality of several woody plant elements, such as *Torreya bilinica, Carya fragiliformis, Acer crenatifolium*, *Sloanea arto-*

carpites, Tilia gigantea and shares many others with the flora of Matrý Hill with additionally *Tilia gigantea, Smilax* and some more so far enigmatic leaf morpho-types. Likewise its more advanced aspects are expressed by *Pinus* needles, *Acer tricuspidatum* and *Ulmus pyramidalis*, but the extensive material housed at the Hungarian Natural History Museum, Budapest and elsewhere awaits a definitive revision.

Maar floras – general aspects

(H. Walther)

The definition of a maar structure is that volcanic lava came into contact with ground water; due to this event, a violent explosion took place. The result of this process is a funnel-like depression. The maars are products of phreatomagmatic eruptions which occur in many ancient and modern volcanic regions. According to Lorenz (1985) and Suhr (1999), they represent small monogenetic volcanoes, mostly in the form of a crater cut in the pre-eruption terrain usually reaching, at maximum, 2 km in diameter and 400 m in depth. They belong to the second most common type of volcanoe in the world.

The maars are formed by explosive volcanic activity at sub aerial plate margins and in intra-plate settings. The reason of such phreatomagmatic activities is the complex interaction between ascending magma and ambient water, mostly groundwater, which give rise to powerful vapour explosions. After these reactions, a close relationship between the surface draining patterns such as valleys and places of phreatomagmatic eruptions can be observed (Lorenz 1985, Suhr 1999). A typical maar structure consists of a maar crater, ring wall and maar lake with its superficial part of the maar.

The preservation of maar structures is evident over longer periods of the earth's history. According to Suhr (1999) it depends on their position in subsidence- or uplift-dominated areas. Maars located in uplifted areas can be eroded to different levels depending on the rate of erosion. The deeper the level of erosion, the greater the difficulties in identifying the remaining features of maar-structures (see Suhr 1999, Lorenz 2000, Schulz et al. 2002, Harms et al. 2003, Lenz et al. 2007, Suhr and Goth 2008). Maars which are located in subsiding areas are buried by younger sediments. This fact prevents the identification of maar structures and their indication on the present surface. Buried maars can be discovered by means of geophysical survey, or incidentally by drillings.

Maars and their significance in fossil plant research in Central Europe is demonstrated here by examples from two places in the surroundings of the Eger rift. From the Czech Republic, maars were described and discussed by Kopecký et al. (1967) and Brus and Hurník (1984). Maar structures of the north-western environs of the Eger Rift in Germany (Saxony, from the Middle Erzgebirge Mts. and Lusation region) were recently identified and discussed by Suhr and Goth (1996, 1999, 2008). From both areas many plant remains have been collected since 1984 and stored in the Senckenberg Collection of Natural History, Museum of Mineralogy and Geology, Dresden, Saxony, in the Institute for Environment and Geology, Freiberg and in the Museum of Natural History, Humboldt University, Berlin. The palaeobotanical examination of two Oligocene maar floras, as reviewed below, demonstrates different types of origin at different times.

Hammerunterwiesenthal (Early Oligocene)

The maar lake of Hammerunterwiesenthal (diameter 1400m) was filled by clastic sediments, such as nephrites and turbidites, from the ring wall of the maar and also from laminated limestone (Böhme 1998, Suhr and Goth 2008, Walther 1998, Walther and Kvaček 2007). Up to now, only one turbidite area has yielded fossils during field work between 1974 and 1998. According to Suhr (1999) and Kvaček and Walther (2001), the K/Ar dating of the locality Hammerunterwiesenthal (tuffites) is 30.48 Ma. In a clear interval of time two magmatic intrusions took place within the freshwater sediments. One is the phonolite of the so called "Richter" quarry in Hammerunterwiesenthal (28.4 Ma) and the other is the tephrite at České Hamry village (Czech Republic, 22.8 Ma) according to Suhr and Goth (2008).

The plant-bearing horizon of laminated tuffite is about 0.10 to 0.40 m thick. Beside plant megafossils, e.g. leaf fragments, more rarely fruits, seeds and fragments of dead wood (twigs), fossils of animals also rarely occur there. Up to now, accumulations of egg shells of snakes *Stagniola* sp. were found there (Schröder-Rogalla et al. 2006). Insects were found only in the form of egg-sets of damselflies, family Coenagrionidae (Hellmund and Hellmund 1998) and in one fragment also *Formicoidea* (Walther 1998). Of the lower vertebrates a complete skeleton of the salamander, *Archeotriton basalticu*s was recovered. This primitive member of the salamanders is endemic to the Lower Oligocene and lowermost Upper Oligocene of the České Středohoří and Lusatia Mts. These animals were excellent swimmers and inhabited the littoral zone of lakes with oligotrophic and meromictic conditions (Böhme 1998).

Leaf fossils are mostly preserved as compressions while impressions are rarer. Therefore, the preparation of macrofossils can be difficult from this hard rock, which originated due to the pressure of the overlying phonolites. Another effect is intensive calcification of the former organic matter of leaf laminas. This type of such coal is called "Magerkohle" (Gindorf et al. 1981, Walther 1998) and is without any fragments of cuticle. The heat radiating from the phonolite overlying the basaltic pyroclastics could be responsible for this coal type. Considering the structure and distribution of sediments, the locality Hammerunterwiesenthal demonstrates an early phase of a maar (Suhr and Goth 1996, Walther 1998), which can be derived from the following scenario: The maars originated in a region covered by a dense Mixed Mesosphytic forest. The explosion completely destroyed the vegetation in the three to four kilometres around the site. The palaeo-climate was warm and humid in the Early Oligocene. Under such conditions, a re-colonisation of vegetation took place in a relatively short time. It seems likely that the re-colonisation did not start in the typical succession manner, instead started with the azonal pioneer vegetation (Walther 1998).

The leaf fossils went from the immediate surroundings of the maar-lake, without long transport, from the natural habitat to the embedding site. Hence they are sub-allochthonous. This view can be proved by the irregular position of about 90 leaves over an area of 510 mm by 240 mm (Gastaldo et al. 1996, Walther 1998). There are also no marks of deformation on the leaf laminas. Another sign of the sub-allochthonous origin of the assemblage can be demonstrated by the dominance of sun leaves in the fossil samples (Roth and Dilcher 1978, Gastaldo et al. 1996, Walther 1998).

The flora of Hammerunterwiesenthal (Table 6) is characterised by an over-representation of lauroids, namely *Daphnogene* and *Laurophyllum*. It is again evidence, that the natural frequency of one species cannot be proved by frequency of fossil samples. In connection with these questions, the abscission time, e.g. "Treiblaubfall" or special influence of edaphic conditions in volcanic areas in relation to the distribution pattern of fossil leaves should be kept in mind (Kvaček and Walther 1995, Walther 1998). It could also be possible, that shrubs or small trees of Lauraceae have played an important role in the process of re-colonisation. Nevertheless, the frequency of the Lauraceae foliage is notable. According to the specimen frequency of typically mesophytic elements, most common are samples of *Daphnogene* and *Laurophyllum*, followed by *Acer* cf. *palaeosaccharinum*, *Tetraclinis salicornioides*, *Craigia bronnii*, cf. *Trigonobalanopsis rhamnoides,* cf. *Carpinus grandis*, *Acer* cf. *integrilobum, Engelhardia macroptera*, *Hydrangea microcalyx*, *Ilex castellii* and cf. *Cercidiphyllum crenatum.* There are also species represented which tolerated more wetland or riverside soils, such as *Ulmus fischeri*, *Pinus* sp., *Alnus* cf. *rostaniana*, *Acer* cf. *tricuspidatum* and *Sabal* sp. But also other species which were not listed above can grow under similar conditions, with the exception of *Tetraclinis salicornioides*. Typical azonal elements, such as *Taxodium* and *Nyssa*, do not occur in this assemblage. Such composition is typical of the majority of the volcanic floras in Central Europe (Kvaček and Walther 1995, 1998, 2001, 2003, 2004, Radoň et al. 2006). These morphospecies give a picture of the Mixed Mesophytic forest growing in the surrounding of the maar, but also covering the maar wall. Along very small streams, which embouchure in the maar lake, a narrow strip of riparian forest with *Alnus*, *Ulmus* and *Acer* cf. *tricuspidatum* could have developed. On turfy mouldered habitat on the riverside, on more swampy soil, *Eotrigonobalanus* and *Sabal* may have been growing.

According to the variability of species, thermophilous morphospecies dominate. These are for example *Daphnogene, Laurophyllum*, *Magnolia*, *Liriodendron*, *Craigia*, *Engelhardia* and *Eotrigonobalanus.* It can be accepted that the palaeoclimate of the mesophytic vegetation at Hammerunterwiesenthal was warm temperate humid with distinct seasons (Walther 1998, Kvaček and Walther 2001).

In connection with the Oligocene "Lowland" or "Near sea floras" we attempt comparisons with adjacent volcanic sites in Central Europe mainly in North Bohemia and regions in northern Saxony.

Considering important accessory elements e.g. *Craigia bronnii*, *Acer* cf. *palaeosaccharinum*, *Hydrangea microcalyx* and *Laurophylum* cf. *acutimontaum* together with the age of the locality of Hammerunterwiesenthal, it corresponds best with the Early Oligocene Volcanic floras from Kundratice, Seifhennersdorf, Hrazený/Pirskenberg and Suletice-Berand. These floras show differences in the stock of morphospecies but important are similarities in the accessory elements (Knobloch 1961, Kvaček and Walther 1995, 1998, 2004, Walther and Kvaček 2007). There are also certain connections to the florulas of the regions of Dvérce and Valeč from the stratovolcano of the Doupov Mts., visible in the common occurrence of *Daphogene cinnamomifolia*, *Tetraclinis salicornioides* and *Ulmus fischeri* (Bůžek et al. 1990, Walther 1998). Regarding the so-called lowland floras (near-lake floras) such as Haselbach between Altenburg and Borna in Saxony (Germany), comparisons are more complicated (Walther in Mai and Walther 1978).

The volcanic floras were decisively influenced by the local palaeo-climate (micro- and mesoclimate) and, according to our experience, by edaphic conditions and also by the growing position within the fossil vegetation. The flora of Hammerunterwiesenthal demonstrates an important part of the vegetation in the immediate surroundings of a maar lake in an early stage. Up to now this is the first example in Central Europe.

Kleinsaubernitz (Late Oligocene)

A core, KS/1970, executed in 1970 at Kleinsaubernitz, north of Bautzen, recovered a maar about 300 m deep covered by Lower Miocene sediments 200 m thick (for details of the geological section see Walther 1999). The maar fill is not independently dated. Only plant fossils, well preserved in fossil-bearing strata are at our disposal for dating. Both macrofossils of leaf compressions and fruits, as well as pollen and spores have been recovered. The occurrence of *Boehlensipollis hohlii* (Krutzsch in Mai 1997) and some new elements among the macrofossils typical of Early Miocene flora (e.g. "*Illicium*" *limburgense*, *Illipophyllum thomsonii, Laurophyllum saxonicum*) together with Olig-

➤Text-fig. 20. Plant elements of the flora of Kleinsaubernitz near Bautzen (coll. Mus. Min. Geol. Dresden). 1 – *Eotrigonobalanus furcinervis* (Rossmässler) Walther et Kvaček, 2 – *Cunninghamia miocaenica* Ettingshausen, 3 – *Daphnogene cinnamomifolia* (Brongniart) Unger, 4 – *Dicotylophyllum* sp., 5 – *Eotrigonobalanus furcinervis* (Rossmässler) Walther et Kvaček, 6 – *Taxodium dubium* (Sternberg) Heer, 7 – *Trigonobalanopsis rhamnoides* (Rossmässler) Kvaček et Walther, 8 – *Sequoia abietina* (Brongniart) Knobloch, 9 – *Pronephrium* cf. *styriacum* (Unger) Knobloch et Kvaček, 10 – *Tetraclinis salicornioides* (Unger) Kvaček, 11 – Juglandaceae gen. et sp., 12 – *Comptonia* cf. *longirostris* Jarmolenko, 13 – *Carpinus grandis* Unger, 14 – *Craigia bronnii* (Unger) Kvaček, Bůžek et Manchester, 15 – *Liriodendron haueri* Ettingshausen, 16 – *Acer haselbachense* Walther, 17 – *Matudaea menzelii* Walther, 18 – *Platanus neptuni* (Ettingshausen) Bůžek, Holý et Kvaček, 19 – *Comptonia difformis* (Sternberg) Berry, 20 – *Laurophyllum pseudoprinceps* Weyland et Kilpper, 21 – *Quercus praekubinyii* Walther, 22 – *Distylium* cf. *heinickei* Walther, 23 – cf. *Cedrela acuminata* (A. Braun) Iljinskaya, 24 – *Fraxinus kvacekii* Walther, 25 – *Cathaya* sp., 26 – *Kadsura senftenbergensis* Jähnichen, 27 – *Alnus rostaniana* Saporta, 28 – *Illipophyllum thomsonii* Kräusel et Weyland, 29 – *Fagus*

saxonica Kvaček et Walther, 30 – *Myrica lignitum* (Unger) Saporta, 31 – *Majanthemophyllum petiolatum* Weber, 32 – *Lithocarpus saxonicus* Walther et Kvaček, 33 – *Ilex knoblochii* Walther, 34 – *Magnolia maii* Walther, 35 – *Sequoia abietina* (Brongniart) Knobloch, 36 – *Cyclocarya* sp., 37 – Theaceae gen. et sp., 38 – *Smilax reticulata* Heer, 39 – "*Illicium*" *limburgense* Kräusel et Weyland, 40 – *Ailanthus prescheri* Walther, 41 – *Taiwania* cf. *schaeferi* Schloemer–Jäger, 42 – *Betula kleinsaubernitzensis* Walther, 43 – *Laurophyllum acutimontanum* Mai, 44 – *Acer* cf. *tricuspidatum* Bronn, 45 – *Celtis* sp., 46 – *Ulmus fischeri* Heer (from Walther 1999, corrected); scale bar = 10 mm.

ocene markers (*Eotrigonobalanus furcinervis*, *Laurophyllum acutimontanum*) and elements typical of the Late Oligocene (*Fagus saxonica*, *Cunninghamia miocaenica*) suggest an Eochattian age (Walther 1999, 2004).

The leaf assemblage consists of diversified conifers and woody dicots (see Table 8, Text-fig. 20). Only *Taxodium* is quantitatively well represented accompanied by a few specimens of *Pinus*, *Tsuga, Cathaya, Tetraclinis, Cunninghamia, Taiwania*, *Sequoia* and *Torreya.* Broad-leaved woody plants are represented by 26 deciduous and 22 evergreen elements, of which evergreens quantitatively, in frequency of specimens, predominate, namely *Eotrigonobalanus* and *Quercus praerhenana*. Other evergreen Fagaceae and Lauraceae are also well diversified including the endemic *Lithocarpus saxonicus* and more widely distributed *Trigonobalanopsis rhamnoides*, *Quercus bavarica*, *Q. praekubinyii,* cf. *Q. lonchitis* of the Fagaceae and *Daphnogene*, *Laurophyllum acutimontanum, L. pseudoprinceps* and *L. saxonicum* of the Lauraceae. Some more thermophilous elements, such as *Platanus neptuni*, *Sloanea, Matudaea* and *Distylium* indicate the position of the flora within the climatic optimum of the Oligocene. Arctotertiary elements are less common, but still quite diversified (*Liriodendron*, *Ulmus*, *Fagus*, *Alnus*, *Betula*, *Carpinus*, *Cyclocarya*, *Salix*, *Acer* and *Fraxinus*) referring the leaf assemblage to the Mixed Mesophytic Forest formation (Walther 1998, 2004). Carpological material is scanty (Mai 1997) and includes both Arctotertiary (*Alnus*, *Liriodendron*) and Palaeotropical elements (*Distylium*, *Retinomastixia*).

Not all recovered plant macrofossils belong to mesophytic vegetation. Some connect with swampy habitats around the maar lake – *Taxodium*, *Alnus*, *Sparganium*, *Scirpus* and some are coal-forming – "*Illicium*" *limburgense*, *Illipophyllum thomsonii* and probably *Quercus praerhenana* (Walther 2004). The site is a typical section of the newly suggested Floral Assemblage Kleinsaubernitz (Walther 1999, p. 154).

In the so-called Guttauer volcanic group (for reconstruction see Suhr and Goth 1999, 2008), a research core Barruth A yielded a different flora, closer to that of Kleinsaubernitz. According to preliminary inspection of this plant assermblage (courtesy Kurt Goth 1999) an important difference can be noted as *Daphnogene* and some other lauroid leaf fossils predominate here (Walther 2004, p. 241).

Conclusions drawn from the differences between volcanic and lowland basin settings

In the eastern Sikhote-Alin' there are several localities of fossil plants of various ages, from Palaeogene to Miocene, which are connected with volcanic complexes of the Late Cretaceous to Palaeocene. Sikhote-Alin' volcanic belt, is built of magmatic rocks of medium to acid composition, and also influenced from the Middle Eocene onwards by the Near-shore andesite-basaltoid volcanic belt.

1) The group of Early Palaeogene, mostly Danian floras, represents an upland derivant of the Tsagayan type of riparian floras of the Far East in Russia and adjacent regions of NE China. These floras are characterized by Pinaceae, Cupressaceae s.l., ancient Betulaceae (*Alnus*, *Betula*, *Palaeocarpinus*, *Corylites*), Juglandaceae and Ulmaceae (*Ulmus furcinervis*) and also elements typical of Early Palaeogene at middle and high latitudes of the Northern Hemisphere, such as *Ginkgo*, *Trochodendroids*, Platanaceae, *Davidia*, *Fagopsis*, *Lindera* including sometimes Late Cretaceous relicts, such as *Elatocladus*, *Nilssonia*, *Protophyllum* etc., Early Palaeogene ferns, such as *Osmunda*, *Onoclea*, *Woodwardia* and also *Equisetum*, characteristically occur only in the Malo-Mikhaylovka flora. This site was situated on the northern end of the belt near its uniting with the overlaying Lower Amur valley. With respect to climate, the floras are warm temperate, without evergreen elements.

2) The floras of the Near-shore Volcanic Belt have little in common with those of the Palaeocene. This is due to a longer hiatus in deposition during the Late Palaeocene and Early Eocene. At those time, erosional processes prevailed in Eastern Sikhote-Alin' and reworked ancient volcanic masses.

Beginning with the earliest floras of the second half of the Middle Eocene to Late Eocene, not less than 5 floras of different age can be recognized, mostly individually characterized by floral composition, a phenomenon typical of volcanic settings.

The first and earliest complex of floras (second half of the Middle Eocene to ?Late Eocene) at Sonje Bay belongs to the remains of volcano-clastic deposits preserved in grabens or erosinal depressions of ancient relief, or in the very base of the volcanic andesite-basaltoid series. In the floras some Early Palaeogene elements survived, such as *Trochodendroides*, *Nyssidium*, *Nordenskioldia*, Platanaceae, *Fagopsis*, *Davidia*, but representatives of extant genera started to appear, which later spread in the Oligocene and Miocene floras (*Fagus*, *Carpinus*, *Alnus*, *Vitis*, *Tilia*, *Fraxinus*, *Acer*, *Nyssa* etc.). Formation of these floras also occurred under conditions of a warm temperate climate and corresponded to a period of "unification" of the floral composition within the Far East (from Koriak to Kamchatka and Southern Primorie). These floras differ from contemporaneous floras in intermountain valleys of the same complex by a higher diversity of conifers, absence of Salicaceae and a minimal representation of Ulmaceae.

The floras in the time interval from the terminal Eocene to beginning of the Miocene are attached to various stratigraphical levels of the subaquatic volcanic period of the Near-shore Andesite-basaltoid Belt. Probably two floral complexes can be distinguished, which originated under conditions of temperate or warm temperate climate at the very beginning of the accumulation of subaquatic volcanic masses (Sjurkum & Siziman, and Amgu). Slightly apart from this group appears the flora of Bui, which arose under warmer climatic conditions. The floras of Siziman and Sjurkum are characterized by occurrences of *Picea*, *Larix*, *Populus*, *Salix*, *Alnaster*, *Rhododendron*, *Myrica* and *Vaccinium*, together with a few more thermophilous plants (legumes, magnolias). The flora Amgu differs in more diversified gymnosperms, which form the basic plant association and consists of *Ginkgo*, *Pseudolarix*, *Tsuga*, *Metasequoia*, *Glyptostrobus* and *Thuja*. The temperate character of the flora is stressed not only by the abundance of conifers but also the Rosaceae that dominated among deciduous shrubby angiosperms. According to the climatic conditions and some general elements, the Amgu flora is most similar to the cold temperate flora of the Khoindzo volcanogenic deposits in West Sakhalin, which is dated to the Oligocene by marine microplankton fauna and molluscs. The climatically cold temperate floras of this level are known from the Green Tuffitic Series of the Hokkaido and Honshu (Tanai 1961, 1963) and the Korean Peninsula (Huzioka 1972). It is noteworthy that the floras of Amgu and Bui characteristically include the first records of *Cragia*.

The floras Dembi and Velikaya Kema from higher levels of the sub-aquatic complex of the Near-shore Volcanic Belt developed under distinctive climatic warming. Judging according to the floristic composition, the mean annual temperature varied by about 5 to 6 degrees more than the previous deterioration phase of the Oligocene. The dominating group of conifers were representatives of Cupressaceae–Taxodiaceae and among amentifers – Fagaceae (possibly representatives of the pioneer vegetation after the volcanic explosions that destroyed the previous forest cover). The representatives of Fagaceae included *Fagus*, *Fagopsis*, *Castanea*, *Quercus* and *Castanopsis*, to which the most thermophillous Betulaceae (*Carpinus*, *Ostrya*) were associated. A group of most thermophillous elements including evergreens, consisted of Magnoliaceae, Lauraceae (*Sassafras*, *Cinnamomum*), *Alfaropsis* (i.e. *Engelhardia*) *koreana* and *Nyssa*. This character allows correlating the floras of Dembi and Velikaya Kema with the contemporaneous floras of the so-called "*Engelhardia* Beds" from the Korean Peninsula and Southern Primorie. Such a correlation is still stressed by the common occurrence of characteristic elements, such as *Craigia*, *Ailanthus*, *Comptonia*, various *Acer* spp. etc.

The youngest of the floristic complexes appears as that from Botchi, which originated from lake deposits in the first break of volcanic activity, before the mass lava flows of the Pliocene – ?Quaternary plateau basalts. In this flora the representatives of Pinaceae, Betulaceae and Rosaceae dominate. The proportion of woody broad-leaved elements is not very high, both with respect to frequency and diversity. This complex reflects a phase of development of forest flora in the Miocene, when the climate became temperate and was only slightly warmer in comparison to the present conditions in Northern Japan and Southern Primorie today.

In Central Europe the Palaeogene volcanic floras of Lusatia, North Bohemia and Erzgebirge Mountains reflect mesophytic climax vegetation from about 38 to 24 Ma. In composition and taphonomy of the assemblages the sites are mostly similar, but in each locality demonstrate particularities. These depend on local edaphic relations and micro- to mesoclimatic conditions. In individual sites, the assemblages may be overrepresented by woody elements, which can demontrate either fine climatic oscillations or particular taphonomic phenomena. The shrubs, herbs and aquatics within the forests are mostly documented by carpological assemblages.

The majority of the sites in Early Oligocene time (Bechlejovice, Kundratice, Seifhennersdorf, Varnsdorf, Hrazený/Pirskenberg) yielded plant assemblages which belong to the Mixed Mresophytic Forest type with a higher representation of deciduous immigrants which arrived in waves into the Central European forest floras (Walther 1994). Previous Late Eocene assemblages, such as Kučlín differ in having a more thermophilous character, althought the site at Roudníky, dated on the Eocene/Oligocene boundary is already much more similar to those of the Early Oligocene. We may assume a sharp climatic deterioration at that time. After the Early Oligocene mild humid climatic phase, warming trends are noticeable by a mixture of archaic elements, such as *Eotrigonobalanus*, *Lithocarpus* and *Majanthemophyllum* in connection with characteristic coal-forming elements of the Early Miocene, like "*Illicium*" *limburgense*, *Kadsura senftenbergensis* as well as *Illipophyllum thomsonii*. There is also an important dominance of evergreen Fagaceae (8 morphospecies) and higher diversity in Cupressaceae s.l. (4 morphospecies), of which *Taxodium* absolutely dominated. *Fagus saxonica* is an important accessory marker suggesting that the warming arose to such an extent that the forests included 50% laurophyllous and 50% deciduous components. This stage was for this reasons established as a new independent Floral Assemblage Kleinsaubernitz. Up to now this is the latest Palaeogene site of volcanic floras in Central Europe. A comparison with West European volcanic floras of similar age, such as Seussen (Knobloch 1971), Enspel (Köhler 1979) and the lowland flora of Mockrena-Witznitz (Mai and Walther 1991) reveals particular similarities in composition, but certainly not a full analogy.

The two studied regions in East Asia and Central Europe share signs of sharp climatic deterioration in the latest Eocene (Amgu, Roudníky), which reached cold temperate conditions in East Asia and warm temperate in Europe. In both regions higher levels of the Oligocene correspond in showing warming trends. The situation in the Palaeocene to Lower Eocene remains unknown for both East Asia and Central Europe because no floras of this time interval are available. The Middle to Late Eocene floral assemblages clearly differ by more thermophile aspects in Central Europe. More accurate objective palaeoclimatic proxy data for East Asian Palaeogene floras are not available and only a few for Central Europe. Therefore the above comparisons must be taken as tentative, awaiting more objective evaluation.

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Explanation of the plates

PLATE 1

Typical elements of the flora of Malo-Mikhaylovka (coll. Geol. Inst. RAS Moscow).

1. Musci gen. et sp., sterile plants, × 2.
2. *Equisetum* sp., rhizome, × 1.
3. *Asplenium dicksonianum* Heer, fragmentary sterile frond, × 1.3.
4. *Metasequoia occidentalis* (Newberry) Chaney, sterile leafy shoot, × 1.6.
5. *Metasequoia occidentalis* (Newberry) Chaney, seed cone, × 1.
6. *Ginkgo* sp., leaf fragment, × 1.4.
7. *Onoclea hebridica* (Forbes) Johnson, fragmentary sterile frond, × 1.1.
8. ? Cupressaceae gen. et sp., leafy shoot, × 1.4.
9. *Ditaxocladus* sp., leafy shoot, × 1.2.
10. *Dennstaedtia tschuktschorum* Kryshtofovich, sterile frond, × 3.
11. *Larix puerensis* Golovneva et Akhmetiev, brachyblast, × 2.5.
12. *Ginkgo* sp., seed, × 2.6.
13. *Nyssidium arcticum* (Kryshtofovich) Iljinskaya, fruits, × 1.4.
14. *Amurocyparis sokoloviae* Golovneva et Akhmetiev, leafy shoot, × 1.3.
15. *Pseudotsuga* sp., seed cone, × 1.5.

16, 17. *Corylites amurensis* Golovneva et Akhmetiev, leaves, × 0.8 and × 2.

PLATE 2

Typical elements of the flora of Takhobe (coll. Geol. Inst. RAS Moscow).

1. *Torreya* sp., twig, × 1.5.
2. *Pityospermum* sp., seed, × 1.5.
3. *Torreya* sp., needle, × 1.5.
4. *Betula* (sect. *Costatae*) sp., fruitlet bract, × 2.
5. *Cupressinocladus sveshnikovae* Ablajev, leafy shoot, × 1.5.
6. *Davidia* sp., (vel *Tiliaephyllum tsagayanicum* Krassilov), leaf, × 0.8.
7. *Sassafras* sp., non-lobed leaf form (vel *Lindera* sp.), × 0.8.
8. *Sassafras* sp., lobed leaf form (vel *Araliaephyllum* sp.), × 0.7.

9, 10. *Betula* sp., leaf with its counterpart, × 1.4.

11. *Trochodendroides arctica* (Heer) Berry (above) and *Alnites* sp. (below), leaves, × 0.7.
12. cf. *Carya* sp., leaflet, × 0.9.
13. *Trochodendroides arctica* (Heer) Berry, leaf, × 1.3.
14. *Trochodendroides arctica* (Heer) Berry, leaf, × 1.5.
15. *Ulmus furcinervis* (Borsuk) Ablajev, small leaf, × 1.7.

PLATE 3

Additional elements of the flora of Takhobe (1-7) and Zerkalnaya (8-10) (coll. Geol. Inst. RAS Moscow).

1. *Ulmus furcinervis* (Borsuk) Ablajev, leaf, × 1.5.
2. *Sorbus* sp., leaf fragment, × 1.1.

3. *Davidia* sp. (vel *Tiliaephyllum tsagayanicum* KRASSILOV), leaf, × 1.3.
4. *Vitiphyllum divaricatum* ABLAJEV, leaf, × 1.4.
5. (?) Rosaceae gen. et sp. (= *Sichotaealiniopteris acuminata* ABLAJEV*)*, compound leaf, × 0.7
6. *Rhus* sp., leaflet, × 2.8.
7. *Betula* sp., fruitlet bract, × 3.
8. *Ziziphoides flabella* (NEWBERRY) CRANE, MANCHESTER et DILCHER*,* leaf, × 1.1.
9. *Dicotylophyllum* sp., leaf, × 1.8.
10. (?) Rosaceae gen. et sp. (= *Sichotaealiniopteris acuminata* ABLAJEV*)*, detail of compound leaf shown in fig. 5, × 7.8.

PLATE 4

Typical elements of the flora of Siziman (coll. Geol. Inst. RAS Moscow).

1. *Dryopteris* sp.*,* sterile pinna, × 1.2.
2. Cupressaceae gen. et sp., foliage shoot, × 2.
3. *Metasequoia occidentalis* (NEWBERRY) CHANEY, foliage shoot, × 1.3.
4. *Larix* sp., brachyblasts with needles, × 1.2.
5. *Picea* sp., seed cone, × 1.5.
6. *Wistaria sikhotealinensis* AKHMETIEV, leaflets, × 0.8.
7. *Zelkova zelkovifolia* (UNGER) BŮŽEK et KOTLABA, foliage shoot, × 0.8.
8. *Leguminosaephyllum* sp., leaf fragment, × 1.5.
9. *Ulmus* sp., leaf, × 1.5.
10. *Zelkova zelkovifolia* (UNGER) BŮŽEK et KOTLABA, leaf, × 2.
11. *Pueraria sizimanica* AKHMETIEV, leaf, × 0.8.
12. *Vitis* sp., leaf, × 2.3.

PLATE 5

Typical elements of the flora of Amgu (except 31 from Bui) (coll. Geol. Inst. RAS Moscow).

1. *Glyptostrobus europaeus* (BRONGNIART) UNGER, leafy twig, × 0.7.
2. *Metasequoia occidentalis* (NEWBERRY) CHANEY, leafy twig, × 0.7.
3. *Sequoia* sp., leafy twig, × 0.7.
4. *Pinus* sp., seed, × 1.5.
5. *Abies amguensis* AKMETIEV et SHEVYREVA, seed, × 1.5.
6. *Pseudolarix klimovae* AKMETIEV et SHEVYREVA, cone scale, × 1.5.
7. *Thuja* sp., twig, × 2.
8. *Berberis* sp., leaf, × 1.6.
9. *Ginkgo adiantoides* (UNGER) HEER, leaf, × 0.7.
10. *Osmunda sachalinensis* KRYSHTOFOVICH, pinna, × 0.8.
11. *Ginkgo adiantoides* (UNGER) HEER, leaf, × 0.7.
12. *Alnus corylina* KNOWLTON, leaf, × 0.9.
13. *Pinus sikhotealinensis* AKMETIEV et SHEVYREVA, seed cone, × 1.
14. *Dicotylophyllum* sp., leaf, × 0.6.
15. *Picea morozovae* AKMETIEV et SHEVYREVA, leafy shoot, × 1.5.
16. *Spirea* sp., leaf, × 0.7.
17. *Leguminosites* sp., leaflet fragment, × 1.5.
18. *Dicotylophyllum* sp., leaf, × 0.8.
19. *Cercidiphyllum crenatum* (UNGER) R. BROWN, leaf, × 1.
20. *Betula* sp., leaf, × 0.8.
21. *Leguminosites* sp., leaflet, × 1.2.
22. *Pinus* sp., needle fascicle, × 0.7.
23. *Acer* sp., leaf fragment, × 1.6.
24. *Dicotylophyllum* sp., leaf, × 1.6.
25. *Dicotylophyllum* sp., leaf, × 3.5.
26. *Dicotylophyllum* sp., leaf, × 0.6.
27. *Palaeocarpinus sikhotealinensis* AKMETIEV et MANCHESTER, fruit (flora of Bui), ×
28. cf. *Tetracentron* sp., leaf, × 0.7.
29. *Dicotylophyllum* sp., leaf, × 0.9.
30. *Dicotylophyllum* sp., leaf, ×
31. *Leguminosites* sp., fruit fragment, × 0.7.
32. *Sorbus lanceolata* TANAI et SUZUKI*,* compound leaf, ×

PLATE 6

Typical elements of the flora of Dembi (coll. Geol. Inst. RAS Moscow).

1. *Fagus palaeocrenata* OKUTSU, leaf, × 0.8.
2. *Pseudolarix* sp., winged seed, × 0.8.
3. *Myrica* sp., leaf base, × 0.8.
4. cf. *Populus basamoides* GÖPPERT, incomplete large leaf, × 0.7.
5. *Ulmus* sp., leaf, × 0.7.
6. *Carpinus subcordata* NATHORST, involucre, × 0.7.
7. cf. *Zelkova zelkovifolia* (UNGER) BŮŽEK et KOTLABA, leaf, × 0.6.
8. cf. *Styrax* sp., leaf, × 0.6.
9. *Chaneya* sp., (= *Astronium ninae* AKHMETIEV et ILJINSKAYA), flower, × 0.9.
10. *Leguminosites* sp., leaflet, × 0.8.
11. Araliaceae gen. et sp., leaf × 0.7.
12. cf. *Fagus antipofii* HEER, leaf, × 0.8.
13. *Hemitrapa* sp., fruit, × 1.4.
14. *Aesculus* sp., leaflet, × 0.7.
15. *Dicotylophyllum* sp. 2, leaf, × 0.7.
16. *Dicotylophyllum* sp. 1, leaf, × 0.7.
17. *Carpinus* sp., involucre, × 0.8.
18. *Ostrya* sp., involucre, × 1.5.
19. *Juglans zaisanica* ILJINSKAYA, leaflet, × 0.7.
20. *Quercus ussuriensis* KRYSHTOFOVICH, leaf, × 0.8.
21. *Vitis* sp., leaf, × 0.5.
22. *Corylus* sp., leaf, × 0.8.
23. *Acer palaeoplatanoides* ENDO var. *macropteris* AKHMETIEV et SCHMIDT, leaf, × 0.5.
24. *Rhus* sp. 2, leaflet, × 0.8.

PLATE 7

Typical elements of the flora of Botchi (coll. Geol. Inst. RAS Moscow).

1. *Abies mariesiformis* AKHMETIEV, cone scale, × 1.2.
2. *Abies sikhotealinensis* AKHMETIEV, leafy twig, HOLOTYPE, × 0.7.
3. *Tilia* sp., leaf, × 0.5.
4. *Alnus* sp., female infructescences, × 1.4.
5. *Alnus protohirsuta* ENDO var. *paucinervis* AKHMETIEV, leaf, × 0.8.
6. *Woodsia pseudomanschuriensis* AKHMETIEV, fertile pinna, × 1.3.
7. *Picea* sp. 2, seed cone, × 0.8.
8. *Ilex* sp., leaf, × 0.8.

9. *Sorbus lanceolata* Tanai et Suzuki, leaflet, × 1.3.
10. *Spirea* sp., leaf, × 0.7.
11. *Crataegus botchiensis* Akhmetiev, leaf, × 0.7.
12. cf. *Populus orzhilanensis* Kornilova, leaf, × 0.7.
13. *Carpinus subcordata* Nathorst, leaf, × 0.8.
14. *Ostrya oregoniana* Chaney, leaf, × 1.2.
15. *Betula kryshtofovichii* Akhmetiev, leaf, × 0.8.
16. *Tripetaleia almquistii* Tanai, leaf, × 0.7.
17. *Craigia oregonensis* (Axelrod) Kvaček, Bůžek et Manchester, spread capsule valve, × 1.3.

PLATE 8

Typical elements of the flora of Kučlín (coll. Hung. Nat. Hist. Mus. Budapest except fig. 11 at Bílina Mines and fig. 14 at Nat. Mus. Praha).

1. *Doliostrobus taxiformis* (Sternberg) Kvaček, cone scale, × 2.2.
2. *Cedrelospermum* sp., leaflet, × 1.3.
3. "*Sterculia*"*crassinervia* (Ettingshausen) Procházka et Bůžek, leaf, × 0.8.
4. *"Acer" sotzkianum* Unger, fruit, × 1.7.
5. *Platanus neptuni* (Ettingshausen) Bůžek, Holý et Kvaček, inflorescence, × 4.2.
6. Nymphaeaceae gen. et sp. indet. ("*Nymphaea*" *polyrrhiza* Ettingshausen), petiole scar, × 0.7.
7. *Daphnogene cinnamomifolia* (Brongniart) Unger, leaf, × 1.
8. *Platanus neptuni* (Ettingshausen) Bůžek, Holý et Kvaček, simple leaf, × 1.5.
9. "*Ficus*" *daphnogenes* Ettinsghausen, leaf, × 0.8.
10. *Sloanea nimrodi* (Ettingshausen) Kvaček et Hably, leaf, × 1.
11. ? *Sabal raphifolia* (Sternberg) Knobloch et Kvaček, leaf fragment, × 0.3.
12. *Dicotylophyllum* sp., leaf, × 1.7.
13. *Laurophyllum* sp., leaf, × 1.6.
14. *Nitophyllites bohemicus* Wilde, Bogner et Kvaček, leaf fragment, × 1.
15. *Apocynospermum striatum* E.M. Reid et Chandler, seed, × 1.7.
16. *Engelhardia macroptera* (Brongniart) Unger, fruit, × 2.

PLATE 9

Typical elements of the flora of Roudníky (coll. Bílina Mines except fig. 4 at Nat. Mus. Praha).

1. *Torreya bilinica* Saporta et Marion, two needles, × 1.7.
2. *Acer angustilobum* Heer, leaf, × 2.2.
3. *Platanus neptuni* (Ettingshausen) Bůžek, Holý et Kvaček, simple leaf, × 1.5.
4. *Juniperus pauli* Kvaček, fertile twig, HOLOTYPE, × 1.7.
5. cf. *Taxodium dubium* (Sternberg) Heer, sterile twigs, × 1.4.
6. *Carpinus mediomontana* Mai, involucre, × 1.
7. *Craigia bronnii* (Unger) Kvaček, Bůžek et Manchester, fruit capsule valve, × 1.7.
8. *Liriodendron haueri* Ettingshausen, fruitlet, 1.8.
9. *Cercidiphyllum crenatum* (Unger) R. Brown, leaf, × 2.
10. *Carya fragiliformis* (Sternberg) Kvaček et Walther, leaflet, × 0.8.

11-12. *Ostrya atlantidis* Unger, fruit bracts, × 1.6 adn 2.

13. *Crataegus pirskenbergensis* Knobloch, leaf, × 1.8.
14. *Zelkova zelkovifolia* (Unger) Bůžek et Kotlaba, leaf, × 0.8.
15. *Rosa milosii* Kvaček et Walther, fruit, × 0.8.
16. *Daphnogene cinnamomifolia* (Brongniart) Unger, leaf, × 2.
17. Leguminosae gen. et sp. indet., leaflet, × 2.
18. *Cyclocarya* sp., leaflet, × 1.3.
19. *Pungiphyllum cruciatum* (A. Braun) Frankenhäuser et Wilde, leaf, × 1.4.
20. *Ulmus fischeri* Heer, leaf, × 1.3.
21. *Mimosites haeringianus* Ettingshausen, detached leaflets, × 1.7.

PLATE 10

Typical elements of the flora of Bechlejovice (coll. Nat. Mus. Praha except fig. 11, 15, 20 in Czech Geol. Surv. Praha and fig. 5 in Charles Univ. Praha).

1. *Platanus schimperi* Saporta, leaf, × 0.8.
2. *Platanus neptuni* (Ettingshausen) Bůžek, Holý et Kvaček, simple leaf, × 0.8.
3. *Torreya bilinica* Saporta et Marion, needle, × 1.
4. *Craigia bronnii* (Unger) Kvaček, Bůžek et Manchester, folded capsule valve, × 1.6.
5. *Rosa lignitum* Heer, composed leaf, × 0.6.
6. *Laurophyllum acutimontanum* Mai, leaf compression, × 1.8.
7. *Cercidiphyllum crenatum* (Unger) R. Brown, juvenile leaf, × 1.2.
8. "*Sterculia*"*crassinervia* (Ettingshausen) Procházka et Bůžek, leaf, × 0.8.
9. *Mimosites haeringianus* Ettingshausen, composed leaf, × 1.2.
10. Rosaceae (cf. *Sorbus*), leaflet, × 0.9.
11. *Carpinus grandis* Unger, leaf, × 1.
12. *Ulmus fischeri* Heer, leaf, × 1.
13. *Ostrya atlantidis* Unger, involucre, × 1.
14. *Carya fragiliformis* (Sternberg) Kvaček et Walther, leaflet, × 1.
15. *Dicotylophyllum deichmuelleri* Kvaček et Walther, leaf, × 1.2.
16. *Carpinus mediomontana* Mai, two fruits on long stalk, × 1.3.
17. *Crataegus pirskenbergensis* Knobloch, leaf, × 0.4.
18. *Zelkova zelkovifolia* (Unger) Bůžek et Kotlaba forma *bechlejovicensis* Kvaček et Walther, leaf, HOLOTYPE, × 0.5.
19. *Tilia gigantea* Ettingshausen, leaf, × 0.6.
20. *Acer palaeosaccharinum* Stur, leaf, × 1.
21. *Ziziphus ziziphoides* (Unger) Weyland forma *bilinica* (Ettingshausen) Kvaček et Walther, leaf base, × 1.2.

PLATE 11

Typical elements of the flora of Seifhennersdorf (coll. Mus. Min. Geol. Dresden).

1. *Osmunda lignitum* (GIEBEL) STUR, frond fragment, × 1.2.
2. *Taxodium dubium* (STERNBERG) HEER, foliage long shoot, × 1.3.
3. *Cephalotaxus parvifolia* (WALTHER) KVAČEK et WALTHER, needle compression, × 2.8.
4. *Laurophyllum acutimontanum* MAI, leaf compression, × 0.8.
5. *Ulmus fischeri* HEER, leaf, × 1.4.
6. *Celtis pirskenbergensis* (KNOBLOCH) WALTHER et KVAČEK, leaf, × 1.5.
7. *Quercus lonchitis* UNGER, leaf, × 1.
8. *Taxodium dubium* (STERNBERG) HEER cone scale 1.5.
9. *Ulmus fischeri* HEER, leaf, × 1.
10. *Engelhardia macroptera* (BRONGNIART) UNGER, involucre, × 0.8.
11. *Diospyros brachysepala* A. BRAUN, calyx, × 1.4.
12. *Cyclocarya* sp., leaflet, × 1.
13. *Saportaspermum dieteri* KVAČEK et WALTHER, seed, × 1.2.
14. *Prunus langsdorfii* KIRCHHEIMER, endocarp impression, × 1.8.
15. *Carpinus mediomontana* MAI , involucre, × 1.
16. *Platanus neptuni* (ETTINGSHAUSEN) BŮŽEK, HOLÝ et KVAČEK, female immature head, × 2.2.
17. *Tetraclinis salicornioides* (UNGER) KVAČEK, twig fragment, × 1.2.
18. *Carpinus roscheri* WALTHER et KVAČEK, leaf, × 2.0.
19. *Dusembaya seifhennersdorfensis* (ENGELHARDT) MAI, seed, × 8.
20. *Potamogeton seifhennersdorfensis* ENGELHARDT, leafy shoot, × 1.3.
21. *Toxicodendron herthae* (UNGER) KVAČEK et WALTHER, leaflet, × 1.4.
22. *Ailanthus prescheri* WALTHER, leaflet, × 1.
23. *Acer rueminianum* HEER, leaf, × 1.1.

PLATE 12

Typical elements of the flora of Matrý (coll. Distr. Mus. Teplice).

1. *Pinus rigios* ETTINGSHAUSEN, needle fascicle, × 1.3.
2. *Acer crenatifolium* ETTINGSHAUSEN, leaf, × 1.
3. *Betula brongniartii* ETTINGSHAUSEN, leaf, × 1.
4. *Acer integrilobum* WEBER, leaf, × 0.9.
5. *Acer crenatifolium* ETTINGSHAUSEN, leaf, × 1.
6. *Calocedrus suleticensis* (BRABENEC) KVAČEK, twig fragment, × 2.
7. *Liriodendron haueri* ETTINGSHAUSEN, fruitlet, × 1.3.
8. *Torreya bilinica* SAPORTA et MARION, needle, × 1.2.
9. *Daphnogene cinnamomifolia* (BRONGNIART) UNGER, leaf, × 1.
10. *Woodwardia muensteriana* (C. PRESL in STERNBERG) KRÄUSEL, pinna, × 1.8.
11. *Alnus rostaniana* SAPORTA, leaf, × 1.5.
12. *Ulmus pyramidalis* GÖPPERT, twig with two leaves, × 1.6.

PLATE 13

Typical elements of the flora of Žichov (coll. Hung. Nat. Hist. Mus. Budapest).

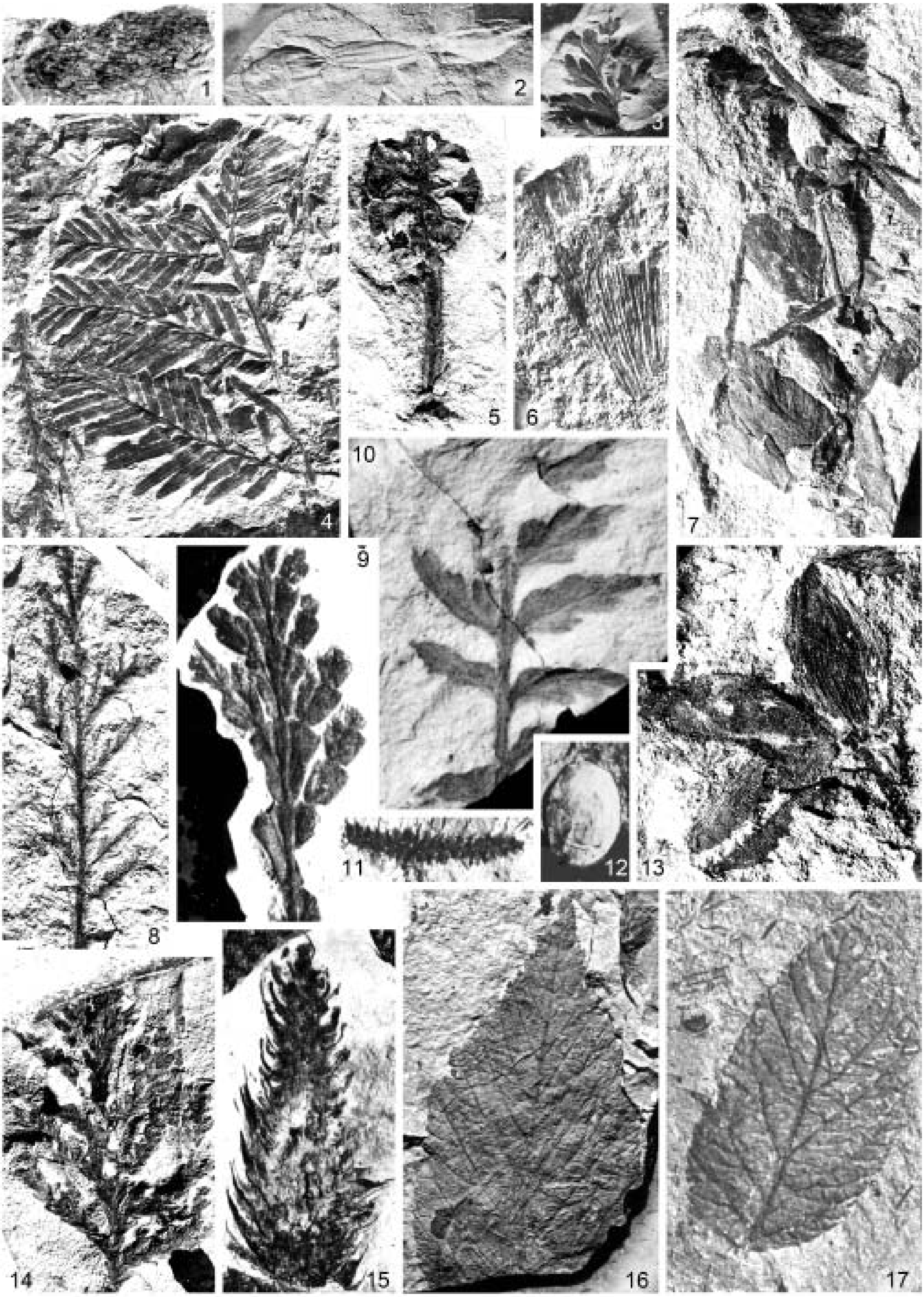
1. *Craigia bronnii* (UNGER) KVAČEK, BŮŽEK et MANCHESTER, fruit valve, × 1.5.
2. *Carya* sp., nut, × 1.
3. *Liriodendron haueri* ETTINGSHAUSEN, leaf, HOLOTYPE, × 0.9.
4. *Carya fragiliformis* (STERNBERG) KVAČEK et WALTHER, leaflet, × 0.9
5. *Platanus neptuni* (ETTINGSHAUSEN) BŮŽEK, HOLÝ et KVAČEK, simple leaf, × 1.
6. *Pinus rigios* ETTINGSHAUSEN, needle fascicle, × 0.9
7. *Sloanea artocarpites* (ETTINGSHAUSEN) KVAČEK et HABLY, leaf, HOLOTYPE, × 0.8.
8. *Torreya bilinica* SAPORTA et MARION, leafy twig, HOLOTYPE, × 1.1.
9. *Ulmus pyramidalis* GÖPPERT, leaf, × 1.5.
10. *Acer crenatifolium* ETTINGSHAUSEN, leaf, × 0.9.
11. *Smilax weberi* WESSEL, leaf, × 1.
12. *Tilia gigantea* ETTINGSHAUSEN, leaf, × 1.

PLATE 14

Typical elements of the flora of Suletice-Berand (coll. Mus. Min. Geol. Dresden except figs 1, 3, 5, 9 in Nat. Mus. Praha).

1. *Calocedrus suleticensis* (BRABENEC) KVAČEK, foliage shoot, HOLOTYPE, × 1.6.
2. *Engelhardia orsbergensis* (WEBER) JÄHNICHEN, MAI et WALTHER, leaflet, × 1.
3. *Tetraclinis salicornioides* (UNGER) KVAČEK, fertile foliage shoot with two opposite seed cones, × 1.3.
4. *Ostrya atlantidis* UNGER, incomplete leaf, × 1.
5. *Populus zaddachii* HEER, leaf, × 1.3.
6. *Craigia bronnii* (UNGER) KVAČEK, BŮŽEK et MANCHESTER, folded capsule valve, × 1.
7. *Sloanea artocarpites* (ETTINGSHAUSEN) KVAČEK et HABLY, leaf, × 1.2.
8. *Engelhardia macroptera* (BRONGNIART) UNGER, involucre, × 0.6.
9. *Hydrangea microcalyx* SIEBER, calyx, × 1.1.
10. *Carpinus grandis* UNGER, leaf, × 1.3.
11. *Platanus neptuni* (ETTINGSHAUSEN) BŮŽEK, HOLÝ et KVAČEK, simple leaf, × 1.1.
12. *Magnolia* sp., leaf, × 1.3.
13. *Laurophyllum* sp., leaf, × 1.2.
14. *Liriodendron haueri* ETTINGSHAUSEN, fruitlet, × 1.5.
15. *Oleinites maii* (BŮŽEK, HOLÝ et KVAČEK) SACHSE, leaf, × 0.6.
16. Leguminosae gen. et sp. indet., leaflet, × 1.6.
17. *Sloanea* sp., fruit valve, × 2.3.
18. *Zelkova zelkovifolia* (UNGER) BŮŽEK et KOTLABA, leaf, × 1.3.
19. *Acer angustilobum* HEER, leaf, × 1.5.

PLATE 1



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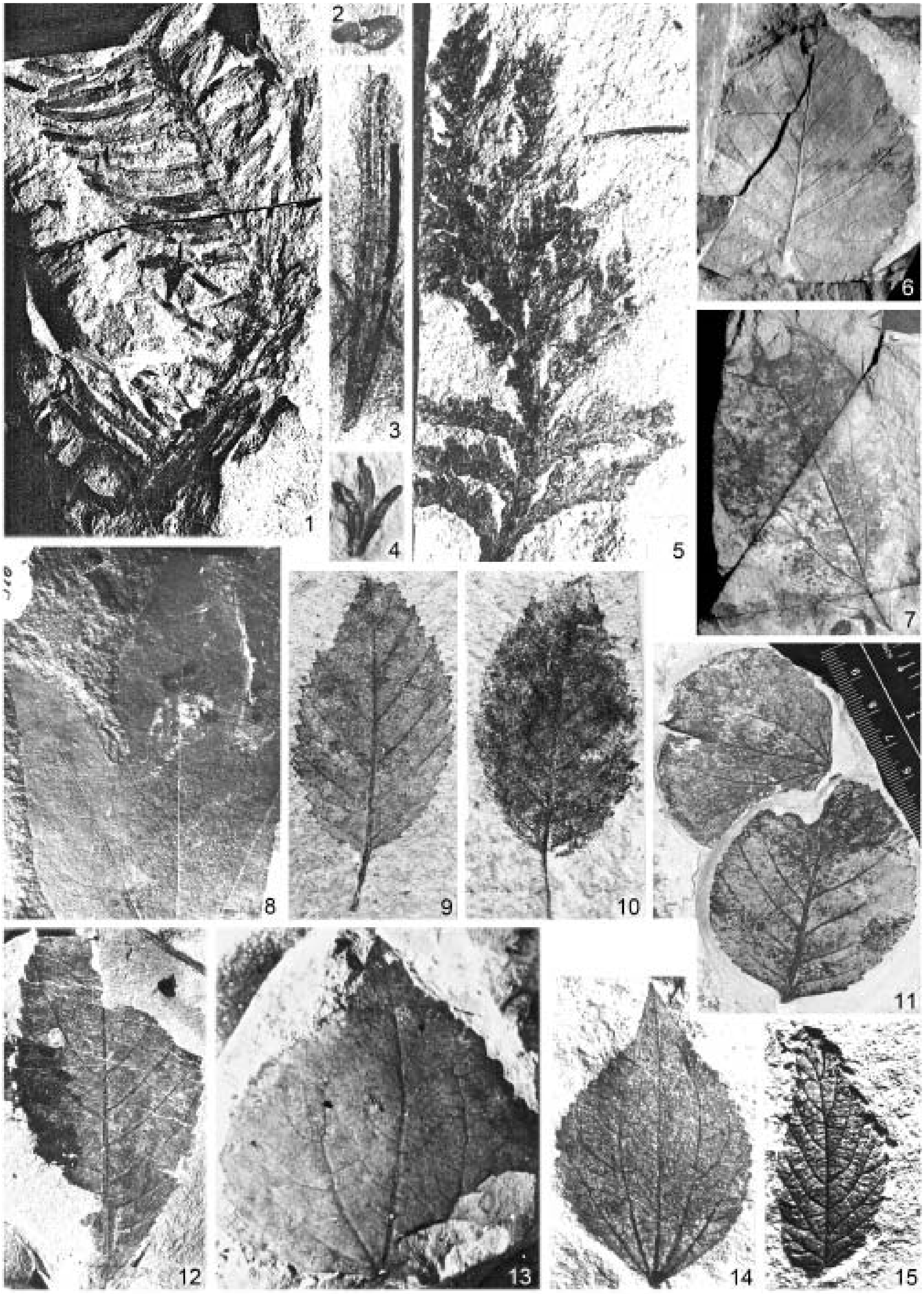

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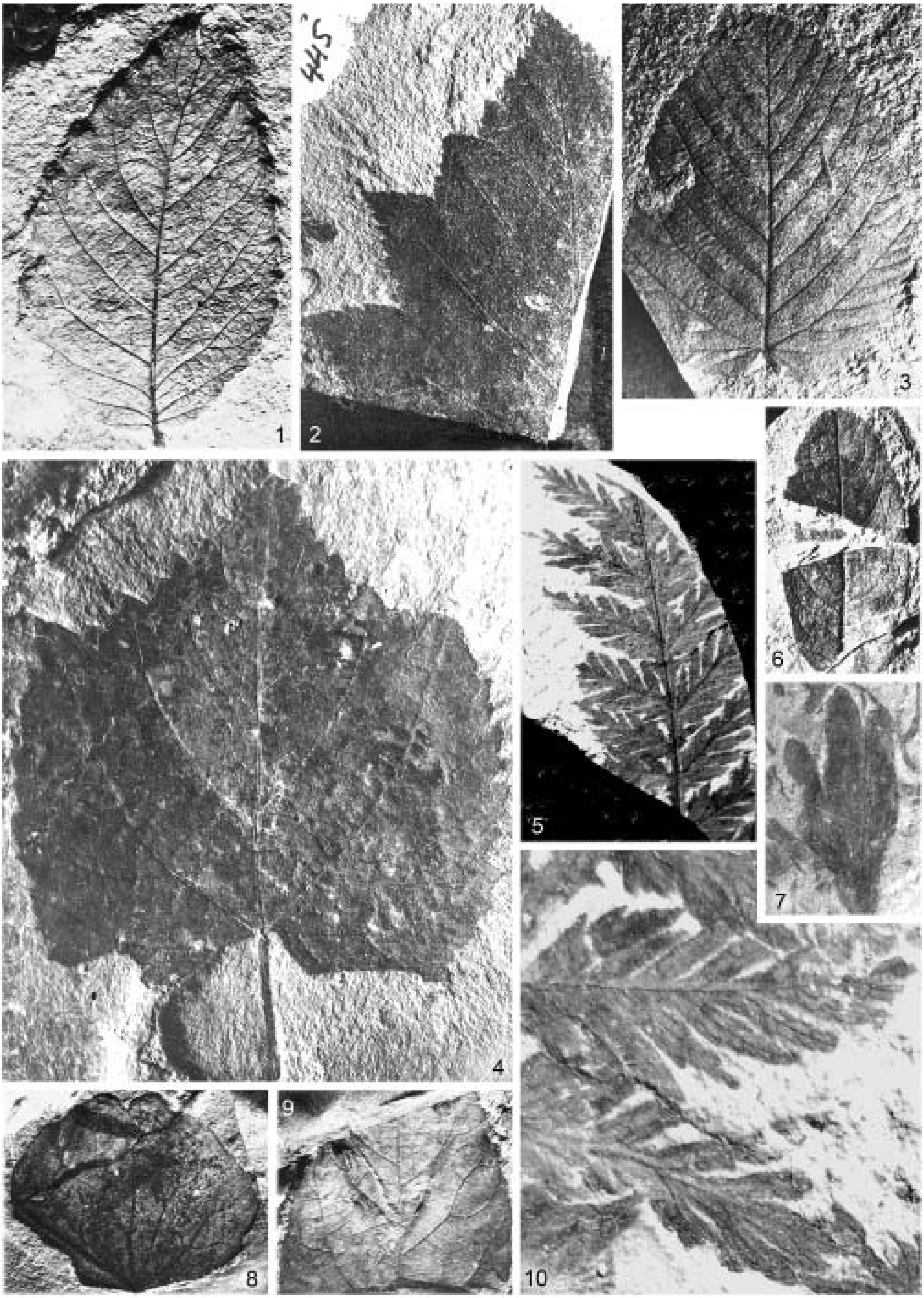

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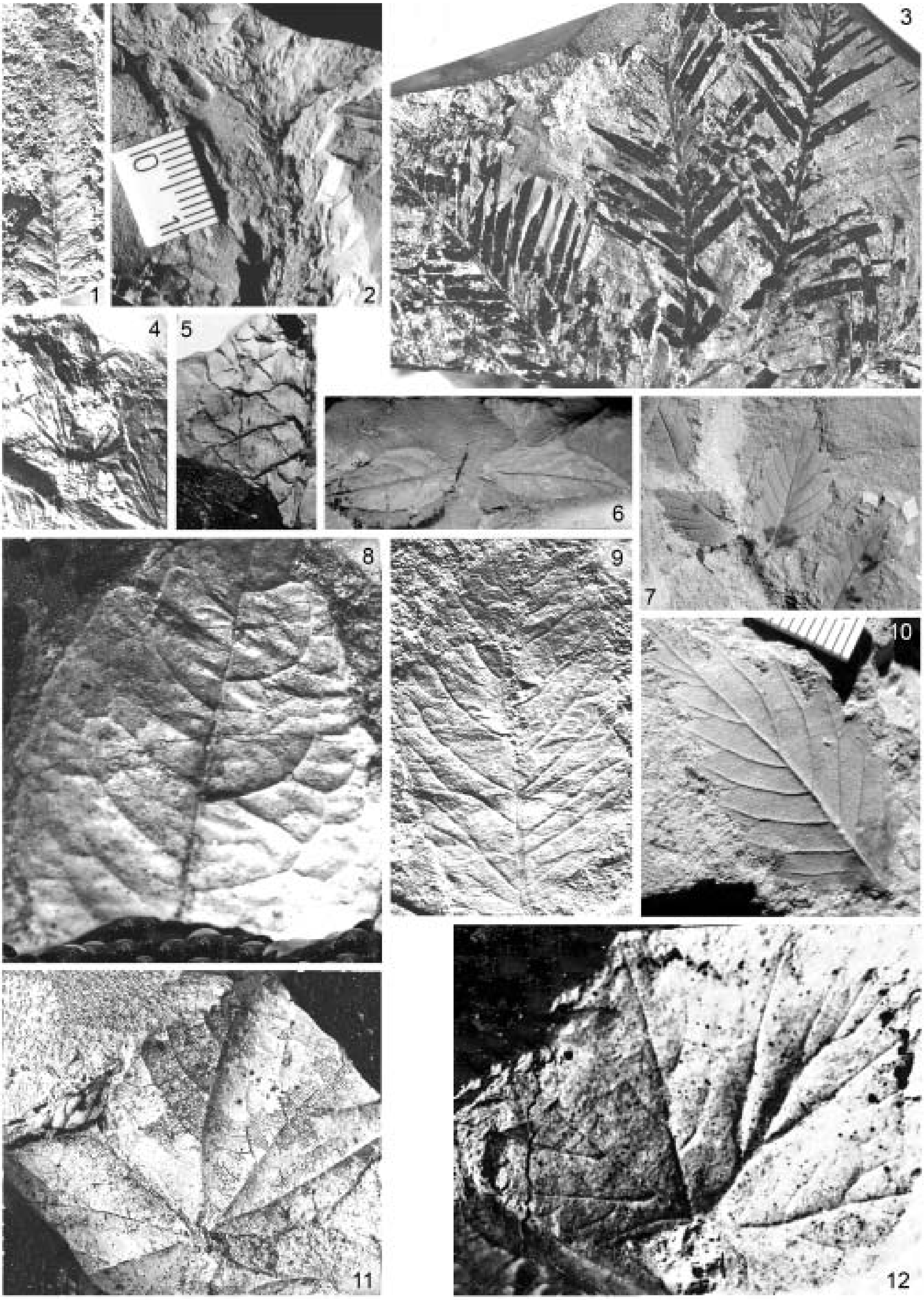

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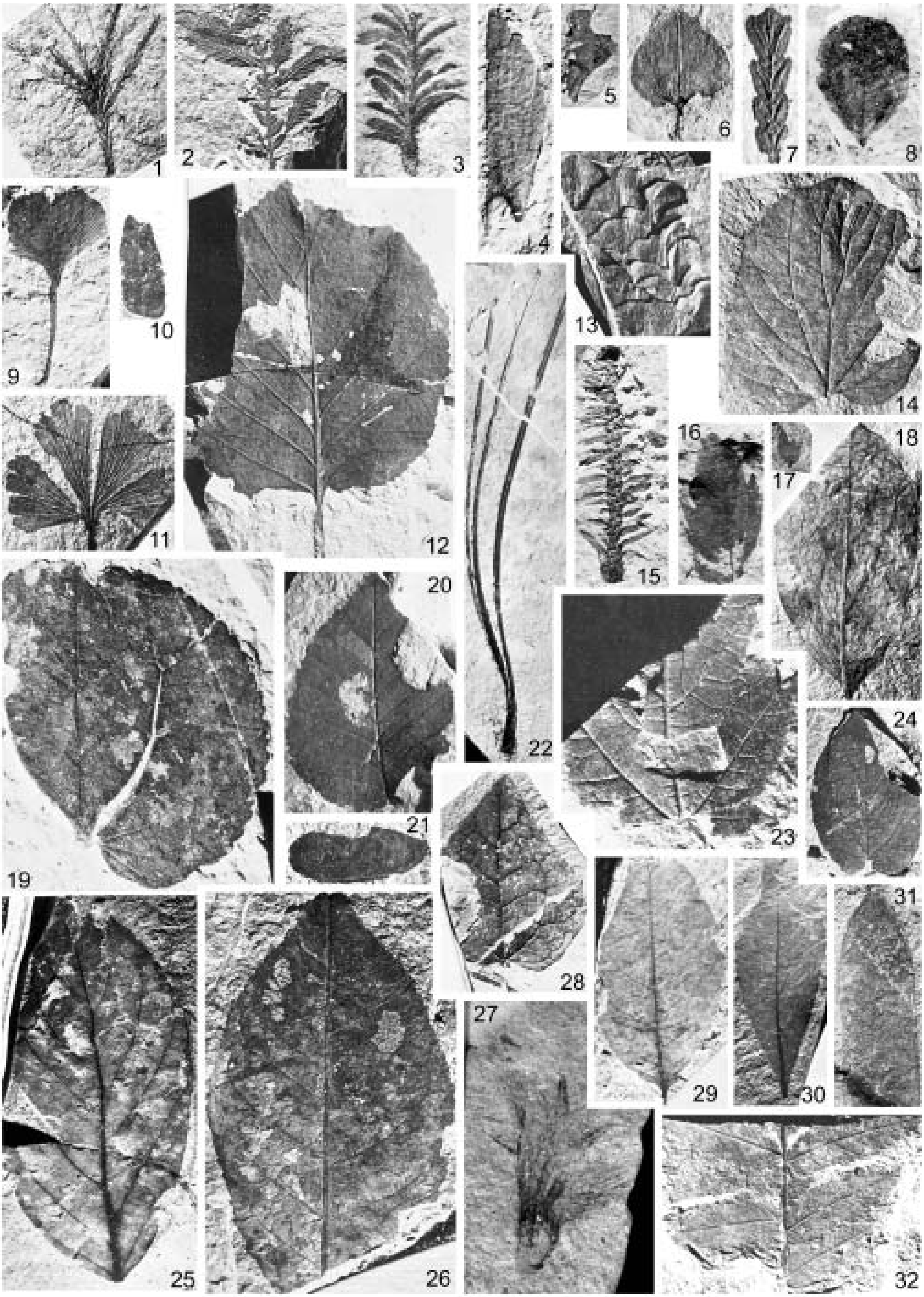
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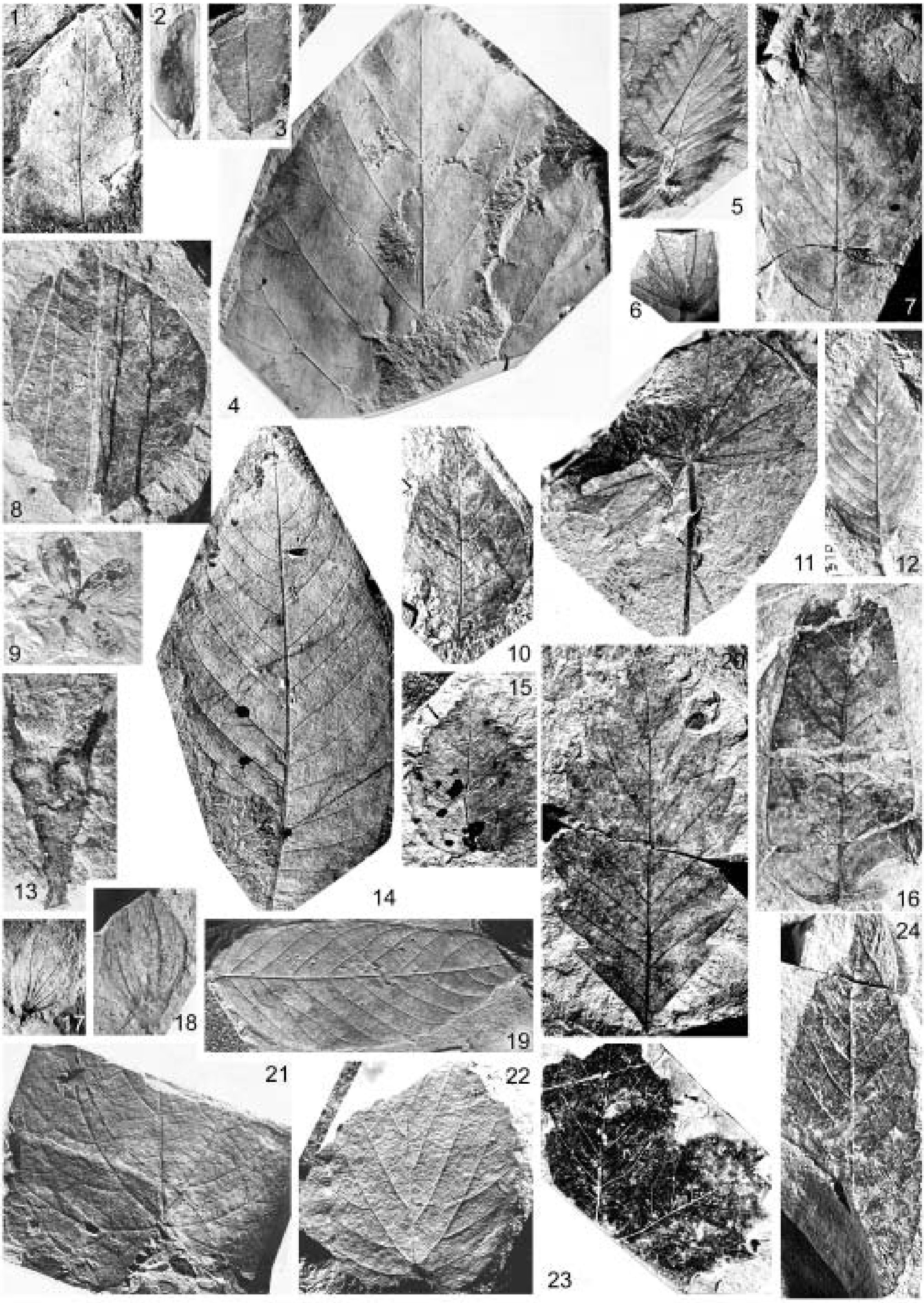
PLATE 6



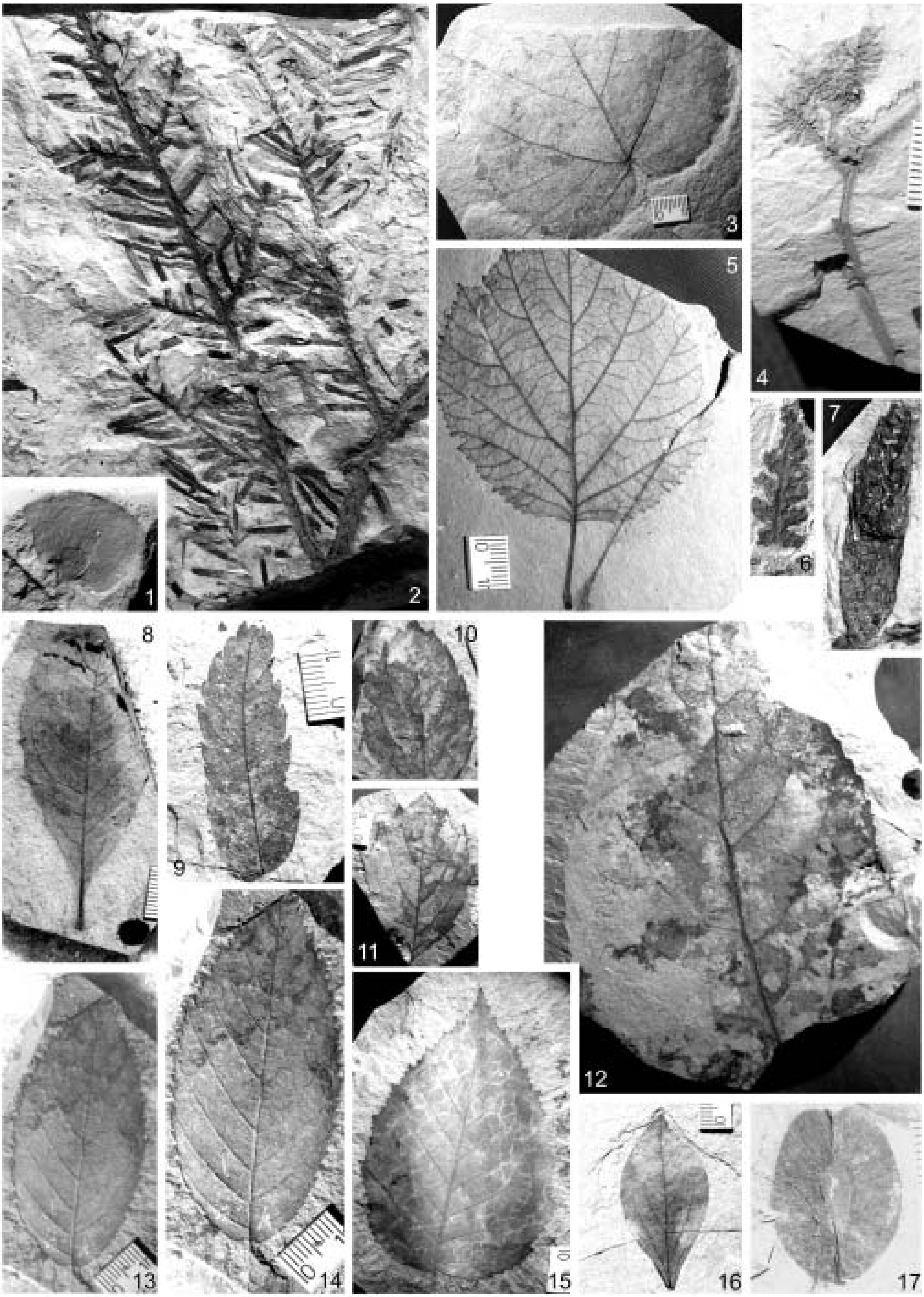

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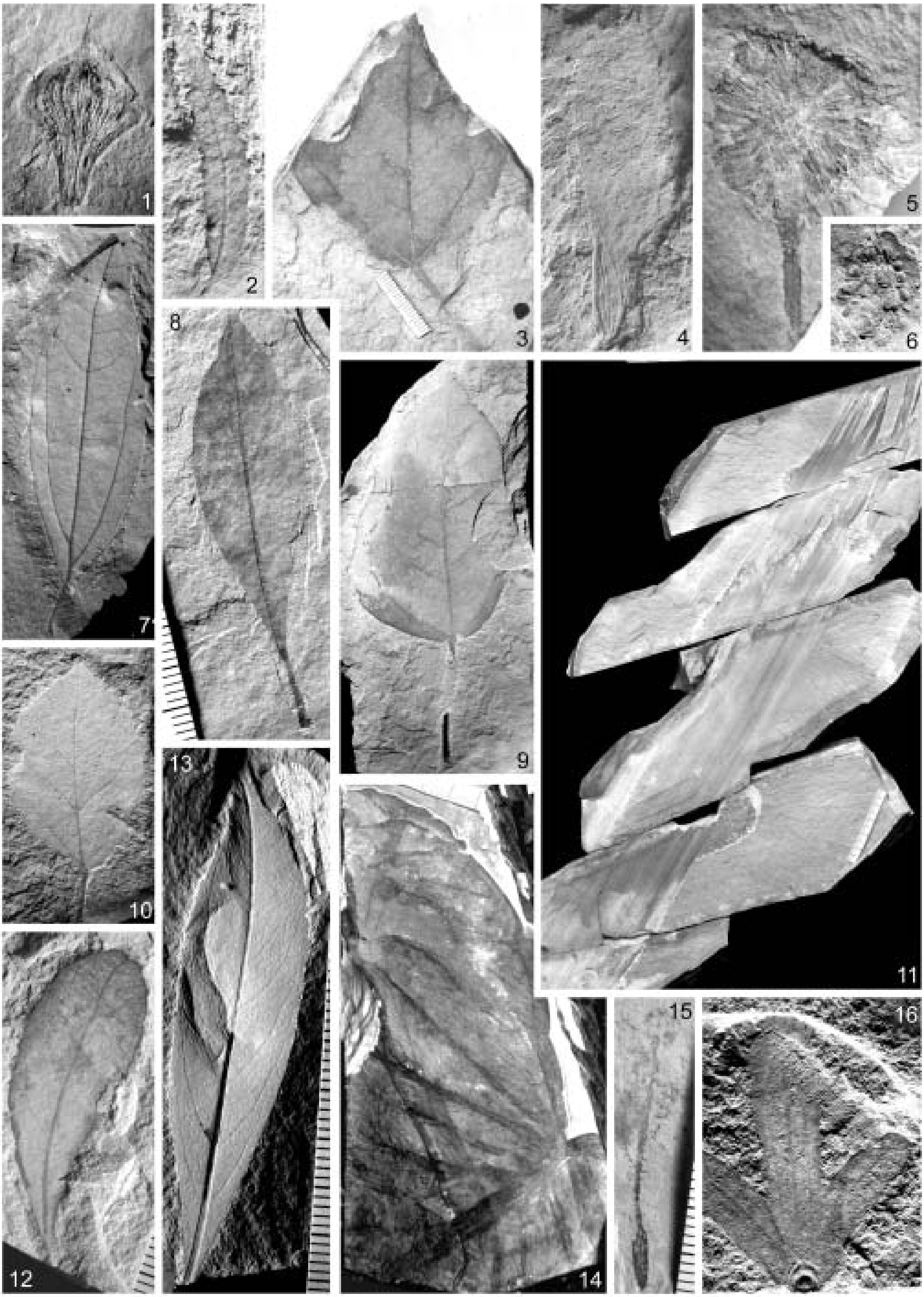
PLATE 8



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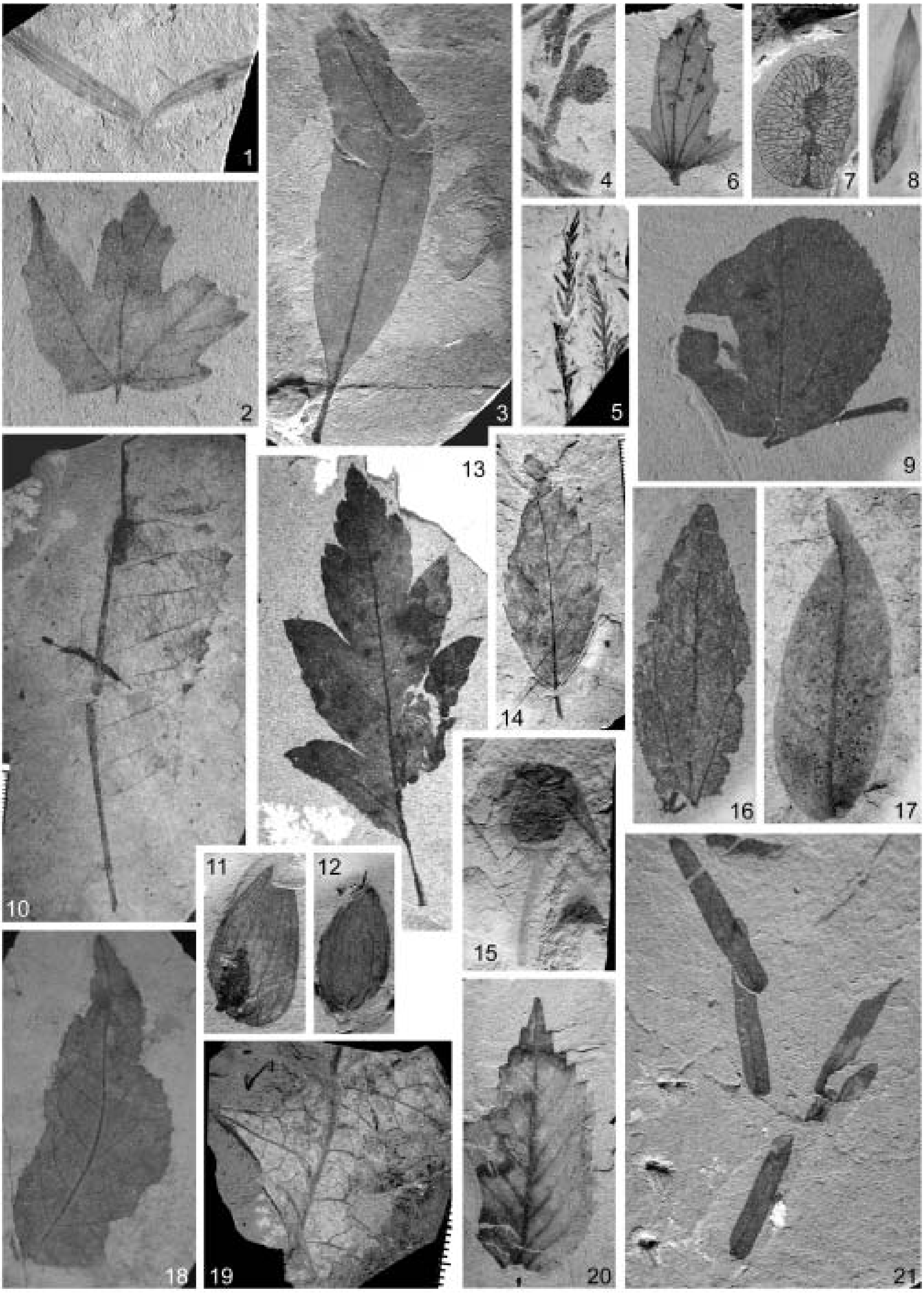

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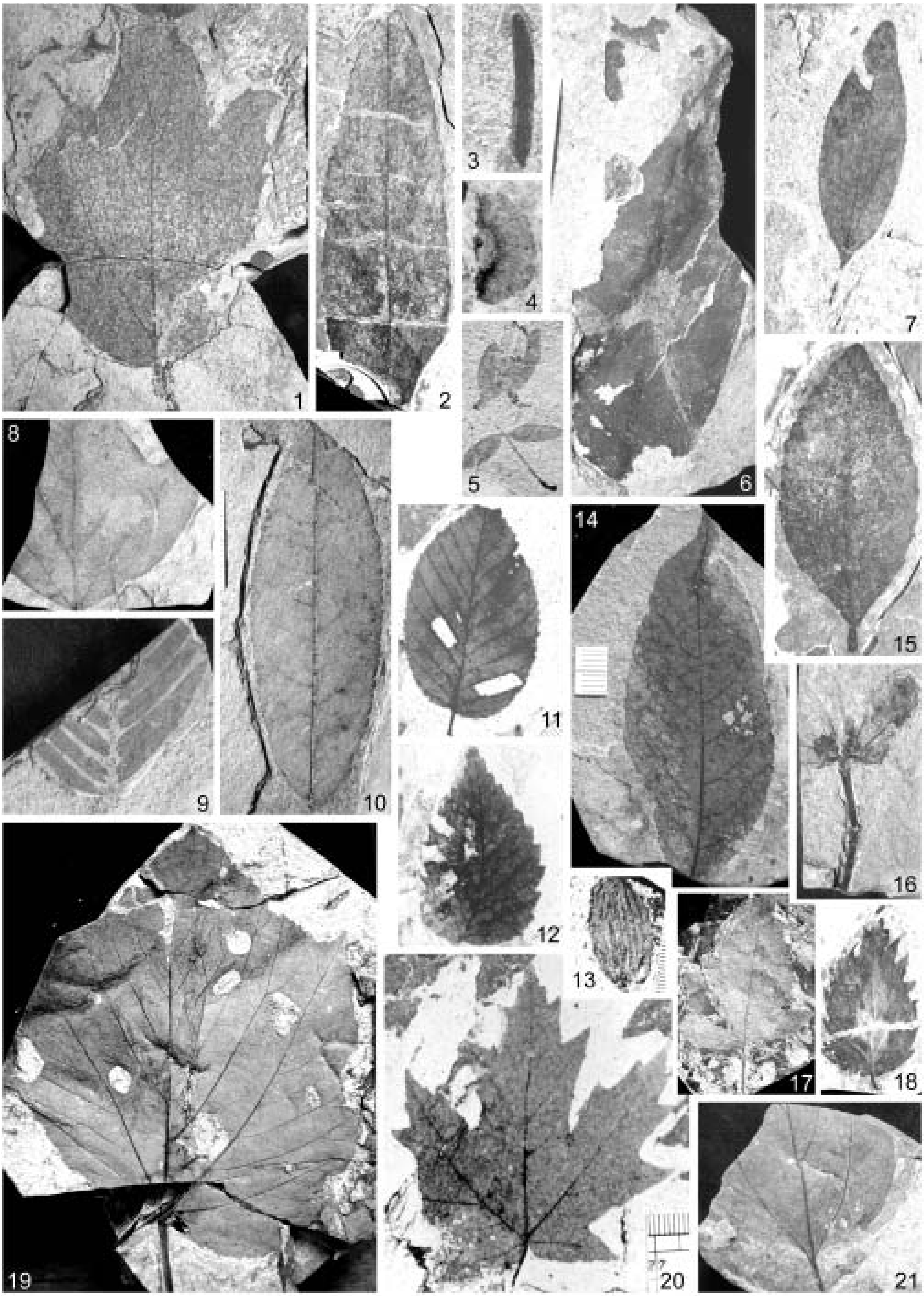


PLATE 11

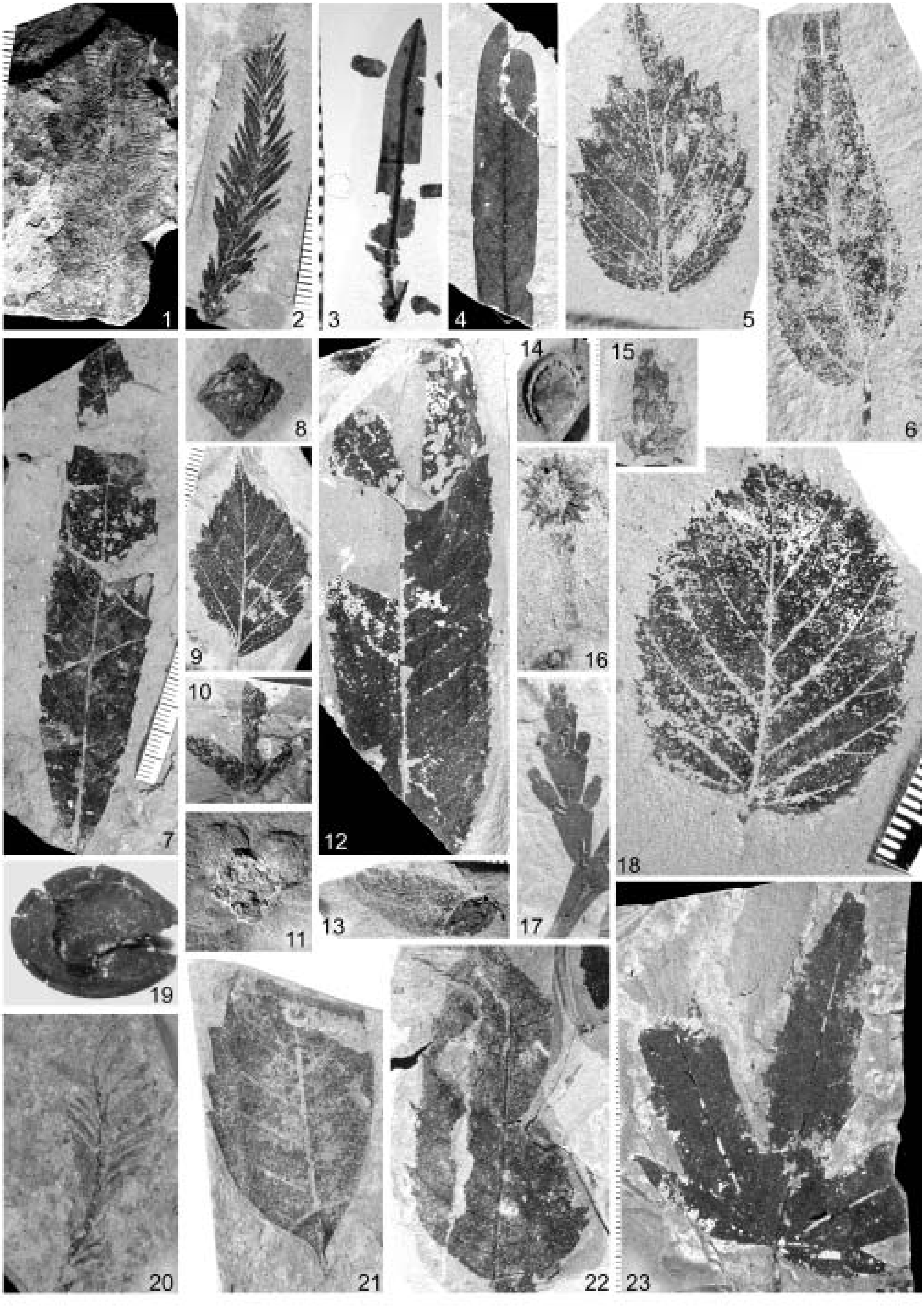
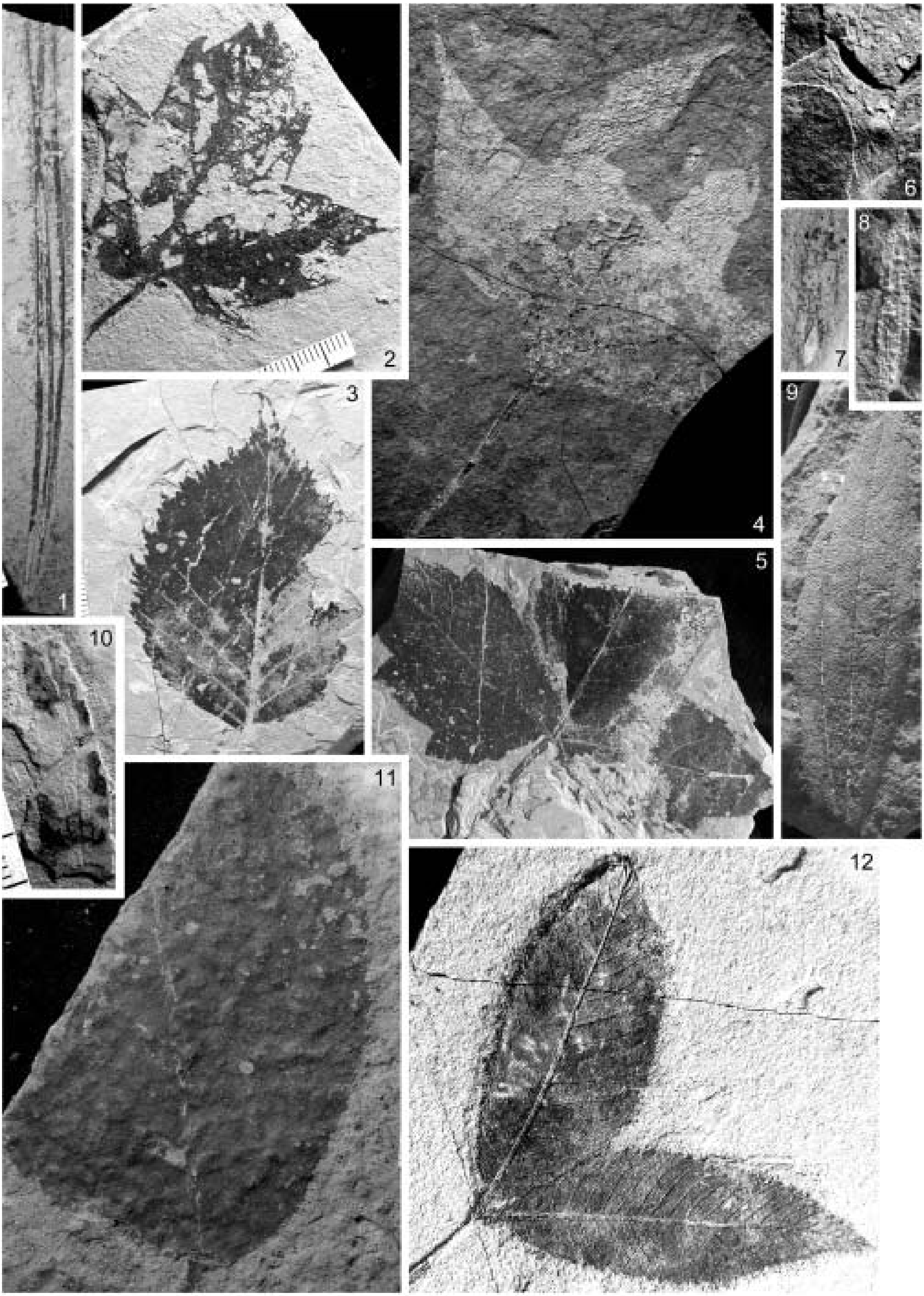


PLATE 12



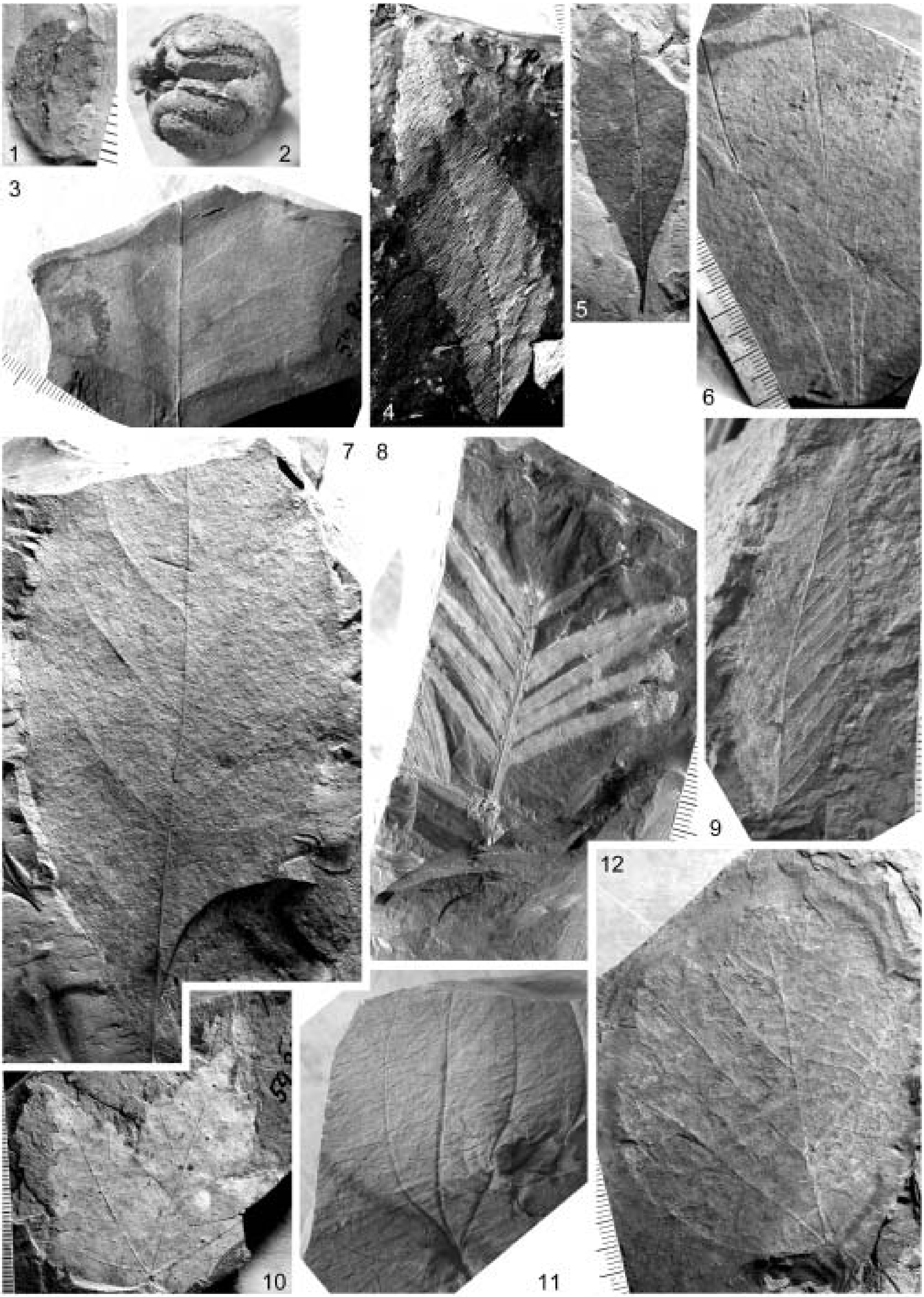

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PLATE 14

Appendix

Table 1. List of the Takhobe flora

taxon	specimens number	%
Ginkgo sp.	2	0.4
Torreya sp.	6	1.2
Araucarites sp.	2	0.4
Picea sp. (seeds)	2	0.4
Pinus sp. (leafy twig)	7	1.4
Pityophyllum spp.	8	1.6
Pityostrobus sp.	3	0.6
Pityospermum spp.	20	4.0
Metasequoia occidentalis (NEWBERRY) CHANEY	94	17.9
Taxodium tinajorum HEER	3	0.6
Glyptostrobus sp.	4	0.8
Cupressinocladus sveshnikovae ABLAJEV	42	8.4
Elatocladus smittiana (HEER) SEWARD	5	1.0
Arundo pseudogoeppertii BERRY	3	0.6
Juglans sp.	1	0.2
Caryaephyllum sp.	2	0.4
Alnus carpinoides LESQUEREUX	30	6.0
Alnites mucronatus ABLAJEV	3	0.6
Betula sp.	1	0.2
Corylites microdentatus (BORSUK) ABLAJEV	19	3.8
Dryophyllum sp.	2	0.4
Fagopsiphyllum sp.	1	0.2
Ulmus furcinervis (BORSUK) ABLAJEV	165	33.0
Menispermites sp.	1	0.2
Lindera sp.	3	0.6
Platanus ex gr. *leucophylla* (UNG.) KNOBLOCH (=*aceroides* GÖPPERT)	4	0.8
Platanus nobilis NEWBERRY	6	1.2
Protophyllum exactum BORSUK	4	0.8
Protophyllum reticulatum ABLAJEV	7	1.4

Sorbus sp.	2	0.4
Rhus sp.	1	0.2
Acer terneicum AKHMETIEV et SCHMIDT	2	0.4
Acer ex group *platanoides* PAX	1	0.2
Cissites sp.	2	0.4
"*Vitis*" *divaricata* ABLAJEV	2	0.4
Vitis tachobensis AKHMETIEV	2	0.4
Tiliaephyllum tsagayanicum (KRYSHTOFOVICH et BAIKOVSKAYA) KRASSILOV	3	0.6
Nyssa bureica KRASSILOV	1	0.2
Viburnum sp.	9	1.8
Trochodendroides arctica (HEER) BERRY	55	11.0
Nyssidium arcticum (HEER) ILJINSKAYA	1	0.2
Araliaephyllum sp.	2	0.4

Table 2. Floral lists of the Botchi Formation in individual fossiliferous levels (1-4)

taxon	1	2	3	4
Muscites sp.		+		
Equisetum sp.				+
Woodsia spedomanschuriensis AKHMETIEV		+		
Abies mariesiformis AKHMETIEV	+	+		
Abies sichote-alinensis AKHMETIEV	+	+	+	
Abies sp. 1	+			
Abies sp. 2			+	
Picea sp. 1	+			
Picea sp. 2		+		
Picea sp. 3	+			
Picea sp. 4	+	+	+	
Picea sp. 5	+	+		
Pinus sp.				+
Larix edelsteinii AKHMETIEV	+	+		+
Larix schmidtiana (PALIBIN) AKHMETIEV	+	+		
Larix sp. 1		+		
Larix sp. 2		+		
Tsuga sp.			+	

taxon	1	2	3	4
Metasequoia occidentalis (NEWBERRY) CHANEY				+
Thuja nipponica TANAI	+	+		
Phragmites sp.		+	+	
Graminophyllum sp.				+
Populus balsamoides GÖPPERT		+	+	
aff. *Carya miocathayensis* HU et CHANEY		+		
Pterocarya krishtofovichii CHELEBAEVA			+	
Alnus protohirsuta var. *paucinervis* AKHMETIEV	+	+	+	+
Alnus schmalhausenii GRUBOV		+	+	
Alnus sp. 1				+
Alnus sp. 2		+		
Alnus sp. 3	+	+		
Betula palibinii AKHMETIEV	+	+		
Betula krishtofovichii AKHMETIEV	+			
Betula (sect. *Costatae* REGEL) sp.	+			
Betula sp. 1				+
Betula sp. 2		+		
Betula sp. 3		+		
Betula sp. 4				+
Carpinus subcordata NATHORST	+	+	+	+
Carpinus lanceolata AKHMETIEV	+	+		+
Carpinus sp.				+
Ostrya oregoniana CHANEY		+		
Corylus sp.		+		
Cercidiphyllum crenatum (UNGER) R. BROWN			+	
Rumex sp.		+		
Craigia oregonensis (AXELROD) KVAČEK, BŮŽEK et MANCHESTER			+	
Spirea sp.			+	
Sorbus lanceolata TANAI et SUZUKI	+	+	+	+

taxon	1	2	3	4
Sorbus borosovae TANAI et SUZUKI				+
Crataegus botchiensis AKHMETIEV			+	
Rubus ovtchininskii AKHMETIEV				+
cf. *Rosa* sp.	+			
Padus miocaenica AKHMETIEV		+		
Phellodendron grandifolium ILJINSKAYA			+	
Rhus pseudotrichocarpa AKHMETIEV		+	+	
Rhus sichote-alinensis AKHMETIEV		+	+	
Ilex sp.	+			
Celastrus sp.				+
Acer trifloriformis AKHMETIEV				+
Acer miotegmentosus TANAI				+
Acer sp. 1				+
Acer sp. 2				+
Acer sp. 3			+	
Acer sp. 4				+
Rhamnella elliptica TANAI			+	
Vitis sp.		+		
Tilia sp.			+	
Tripetaleia almquistii TANAI				+
Acanthopanax (?) *sicho-elinensis* AKHMETIEV		+		
Nyssa pseudoaquatica AKHMETIEV		+		
Fraxinus sp.			+	+
Lonicera mulpensis AKHMETIEV		+		
Lonicera sp.				+
Phyllites sp.	+	+		
Eucommia sp.		+		

Table 3. Comparative lists of the floras of Kučlín and Staré Sedlo Formation

taxon	Kučlín	Staré sedlo Fm.
"Acer" sotzkianum UNGER	*	
Acrostichum lanzeanum (VISIANI) CHANDLER	*	*
Ailanthus sp.	*	
Apocynospermum striatum E. M. REID et CHANDLER	*	
Arecaceae gen. et sp. indet.	*	*
Blechnum dentatum (GÖPPERT) HEER	*	
Callistemophyllum bilinicum ETTINGSHAUSEN	*	
Cedrelospermum leptospermos (ETTINGSHAUSEN) MANCHESTER	*	
Cedrelospermum sp.	*	
Daphnogene cinnamomifolia (BRONGNIART) UNGER	*	*
Doliostrobus taxiformis (STERNBERG) KVAČEK	*	?
Dryophyllum cf. *altenburgense* KNOBLOCH et KVAČEK		*
Engelhardia macroptera (BRONGNIART) UNGER	*	
Engelhardia orsbergensis (WEBER) JÄHNICHEN, MAI et WALTHER	*	
Eotrigonobalanus andreanszkyi (MAI) WALTHER et KVAČEK		*
Eotrigonobalanus furcinervis (ROSSMÄSSLER) WALTHER et KVAČEK	*	*
"*Ficus*" *daphnogenes* ETTINGSHAUSEN	*	
Hooleya hermis E. M. REID et CHANDLER	*	
Hydrangea microcalyx SIEBER	*	
Laurophyllum sp.	*	*
Leguminosae gen. et sp. indet.		*
"*Magnolia*" *longipetiolata* ETTINGSHAUSEN	*	
Majanthemophyllum basinerve (ROSSMÄSSLER) KNOBLOCH et KVAČEK		*
Matudaea menzelii WALTHER	?	
Nymphaeaceae gen. et sp. indet	*	
Nitophyllites bohemicus WILDE, BOGNER et KVAČEK	*	
Palaeohosiea bilinica (SIEBER) KVAČEK et BŮŽEK	*	
Pinus sp. div.		*

taxon	Kučlín	Staré sedlo Fm.
Platanus neptuni (ETTINGSHAUSEN) BŮŽEK, HOLÝ et KVAČEK	*	
Pungiphyllum cruciatum (A. BRAUN) FRANKENHÄUSER et WILDE	*	
Pungiphyllum cf. *waltheri* FRANKENHÄUSER et WILDE	*	
Pronephrium stiriacum (UNGER) KNOBLOCH et KVAČEK	*	
Quasisequoia couttsiae (HEER) KUNZMANN		*
Quercus aff. *haraldii* KNOBLOCH et KVAČEK		*
Raskya venusta (ETTINGSHAUSEN) MANCHESTER et HABLY	*	
Rumohra recentior (UNGER) BARTHEL	*	
Sabal raphifolia (STERNBERG) KNOBLOCH et KVAČEK	?	*
Saportaspermum cf. *occidentale* MEYER et MANCHESTER	*	
Saxifragites crenulatus ETTINGSHAUSEN	*	
Sloanea artocarpites (ETTINGSHAUSEN) KVAČEK et HABLY	*	
Sloanea nimrodi (ETTINGSHAUSEN) KVAČEK et HABLY	*	
Sloanea sp.	*	
Steinhauera subglobosa C. PRESL in STERNBERG		*
"*Sterculia*" *crassinervia* (ETTINGSHAUSEN) PROCHÁZKA et BŮŽEK	*	
"*Sterculia*" *labrusca* UNGER	*	*
Taxodium dubium (STERNBERG) HEER		*
Tetraclinis salicornioides (UNGER) KVAČEK	*	
Trigonobalanopsis rhamnoides (MAI) KVAČEK et WALTHER		*
Ziziphus ziziphoides (UNGER) WEYLAND	*	

Table 4. Comparative lists of the floras of Roudníky, Bechlejovice, Kudratice, Suletice-Holý Kluk, Markvartice, Matrý and Hrazený

taxon	R – Roudníky	B – Bechlejovice	K – Kundratice	S – Suletice, Holý Kluk	Mar – Markvartice	Mat – Matrý	H – Hrazený
Acer angustilobum HEER	*	*	*	*	*	*	?
Acer dasycarpoides HEER sensu PROCHÁZKA et BŮŽEK			*				
Acer engelhardtii WALTHER							
Acer integrilobum WEBER		*	*	*			
Acer palaeosaccharinum STUR	*	*	*	*	*		*
Acer pseudomonspessulanum UNGER				*			
Acer rueminianum HEER			*				
“Acer” sotzkianum UNGER				*			
Acer tricuspidatum BRONN sensu PROCHÁZKA et BŮŽEK		*	?	*	*		
Acer crenatifolium ETTINGSHAUSEN						*	
Ailanthus prescheri WALTHER		*	*	*	*		*
Alnus gaudinii (HEER) KNOBLOCH et KVAČEK	*	*	*		*	*	*
Alnus kefersteinii (GÖPPERT) HEER		*	*			*	*
Alnus rostaniana SAPORTA						*	
Ampelopsis hibschii BŮŽEK, KVAČEK et WALTHER		*	*	*			
Ampelopsis cf. *ludwigii* (A. BRAUN) DOROFEEV					*		
Ampelopsis rotundata CHANDLER		?		?			
Apocynospermum striatum E. M. REID et CHANDLER			*	*			
Arecaceae gen. et sp. indet.		*			*		
Betula brongniartii ETTINGSHAUSEN					*	*	*
Betula alnoides ENGELHARDT – *B. dryadum* BRONGN.		*	*	?	*		*
Calocedrus suleticensis (BRABENEC) KVAČEK				*			
Carpinus cordataeformis MAI		*					*
Carpinus mediomontana MAI	*	*		*			
Carpinus grandis UNGER	*	*					

taxon	R	B	K	S	Mar	Mat	H
Carpinus grandis UNG.		*	*	*		?	*
Carya costata (C. PRESL) UNGER			?				
Carya fragiliformis (STERNBERG) KVAČEK et WALTHER	*	?	*	*	*	*	*
Carya sp.		*		*	*		
Celtis ? bohemica ENGELHARDT				*			
Celtis pirskenbergensis (KNOBLOCH) KVAČEK et WALTHER				*			*
Cephalotaxus parvifolia (WALTHER) KVAČEK et WALTHER			*	?			
Cercidiphyllum crenatum (UNGER) R. BROWN		*	*	*	*	*	*
Comptonia difformis (STERNBERG) BERRY		?		*			*
Cornus studeri HEER		*	*	*			*
Craigia bronnii (UNGER) KVAČEK, BŮŽEK et MANCHESTER		*	*	*	*	*	*
Crataegus pirskenbergensis KNOBLOCH	*	*	?				*
Cyclocarya sp.		*		?			*
Daphnogene cinnamomifolia (BRONGNIART) UNGER			*	*	*	*	*
Dicotylophyllum deichmuelleri KVAČEK et WALTHER	*	*	*	*			*
Dicotylophyllum heerii (ENGELHARDT) KVAČEK et WALTHER		*	*	*			
Diospyros brachysepala A. BRAUN sensu HANTKE		*					
Dombeyopsis lobata UNGER		*	*	*			
Dusembaya seifhennersdorfensis (ENGELHARDT) MAI			*	?	?		
Engelhardia macroptera (BRONGNIART) UNGER				*	*		*
Engelhardia orsbergensis (WEBER) JÄHNICHEN, MAI et WALTHER			*	*	*		*
Fraxinus sp.			*				
Hydrangea microcalyx SIEBER				*			
Ilex castellii KVAČEK et WALTHER			*				
Juglandaceae gen. et sp. indet.			*				*
Laurophyllum acutimontanum MAI		*		?	*	?	
Laurophyllum markvarticense KVAČEK					*		
Laurophyllum medimontanum KVAČEK	*			?	*	?	*
Laurophyllum pseudoprinceps WEYLAND et KILPPER		?	*	?	*	*	?
Leguminosites cladrastoides KVAČEK et WALTHER		*					

taxon	R	B	K	S	Mar	Mat	H
Leguminosae gen. et sp. indet.	*	*		*		*	*
Liriodendron haueri ETTINGSHAUSEN				*		*	*
Magnolia burseracea KIRCHHEIMER		*		?			
Magnolia sp. div.		?	*	*	?	?	
Mahonia pseudosimplex KVAČEK et WALTHER		*		?			
Matudaea menzelii WALTHER		?		?	?		
Meliosma miesleri MAI					*		
Mimosites haeringianus ETTINGSHAUSEN	*	*	*	*			*
Nyssa disseminata (LUDWIG) KIRCHHEIMER					?		
Oleinites maii (BŮŽEK, HOLÝ et KVAČEK) SACHSE				*	*		
Osmunda lignitum (GIEBEL) STUR		*		?			
Ostrya atlantidis UNGER	*	*	*	*	*		
Palaeohosiea suleticensis KVAČEK et BŮŽEK				*			
Pinus sp. div.						*	
Platanus schimperi SAPORTA		*					
Platanus neptuni (ETTINGSHAUSEN) BŮŽEK, HOLÝ et KVAČEK	*	*	*	*	*	*	*
Polypodium radonii KVAČEK		*		*			
Populus zaddachii HEER		*	*	*			*
Potamogeton sp.					*		
Pungiphyllum cruciatum (A. BRAUN) FRANKENHÄUSER et WILDE	*	*	*	*			
Pronephrium stiriacum (UNGER) KNOBLOCH et KVAČEK				*	*		
Prunus langsdorfii KIRCHHEIMER					*		
Pyracantha kraeuselii WALTHER	?	?					
Quercus bavarica (KNOBLOCH et KVAČEK) KVAČEK		?					
Rosa lignitum HEER	*	*	*	*	*	?	*
Rosa milosii KVAČEK et WALTHER	*	*					
Rosaceae (*Cotoneaster* sp. / *Crataegus* sp.)		*			*		
Rumohra recentior (UNGER) BARTHEL		*		?			
Sabal raphifolia (STERNBERG) KNOBLOCH et KVAČEK					*		
Salvinia sp.		*					
Saportaspermum cf. *occidentale* MEYER et MANCHESTER		*			*	*	

taxon	R	B	K	S	Mar	Mat	H
Sloanea artocarpites (ETTINGSHAUSEN) KVAČEK et HABLY		?	*	*	*	*	
Sloanea sp.				*	*		
Smilax weberi WESSEL		*	?	*		*	*
Sparganium sp.					*		
"*Sterculia*"*crassinervia* (ETTINGSHAUSEN) PROCHÁZKA et BŮŽEK		*					
Stratiotes sp.		*					
Taxodium dubium (STERNBERG) HEER	cf.						*
Taxus engelhardtii KVAČEK			*			?	
Tetraclinis salicornioides (UNGER) KVAČEK			*	*		*	*
Tilia gigantea ETTINGSHAUSEN		*	*	*		*	
Toddalia sp.					*		
Torreya bilinica SAPORTA et MARION	?	*	*	?	?	*	
Toxicodendron herthae (UNGER) KVAČEK et WALTHER		*	*				*
Typha latissima A. BRAUN		*					*
Ulmus fischeri HEER	*	*	*	*			*
Ulmus pyramidalis GÖPPERT						*	
"*Viburnum*" cf. *atlanticum* ETTINGSHAUSEN		*		*	*	*	*
Vitis stricta (HEER) KNOBLOCH			?				
Vitis teutonica A. BRAUN				*			
Woodwardia muensteriana (C. PRESL in STERNBERG) KRÄUSEL						*	
? Zamiaceae		*					
Zanthoxylon sp.				?	?		
Zelkova zelkovifolia (UNGER) BŮŽEK et KOTLABA	*	*	*	*			*
Ziziphus ziziphoides (UNGER) WEYLAND		*					

Table 5. List of the flora of Seifhennersdorf

Taxon	frequency of specimens (frequency categories: + - 1 to 9, ++ - 10 to 39, +++ - 40 to 100, ++++ - over 100)
Osmunda lignitum (GIEBEL) STUR	(+)
Pronephrium stiriacum (UNGER) KNOBLOCH et KVAČEK	(+)
Salvinia sp.	(+)
Taxodium dubium (STERNBERG) HEER	(++++)
cf. *Quasisequoia couttsiae* (HEER) KUNZMANN	(+)
Tetraclinis salicornioides (UNGER) KVAČEK	(+++)
Torreya bilinica SAPORTA et MARION	(++)
Cephalotaxus parvifolia (WALTHER) KVAČEK et WALTHER	(+)
Magnolia cf. *denudataeformis* DOROFEEV	(+)
Magnolia seifhennersdorfensis WALTHER	(+++)
Laurophyllum acutimontanum MAI	(+++)
Laurophyllum pseudoprinceps WEYLAND et KILPPER	(+)
Laurophyllum meuselii WALTHER et KVAČEK	(+)
Laurophyllum sp.	(++++)
Daphnogene cinnamomifolia (BRONGNIART) UNGER forma *cinnamomifolia*	(++)
Daphnogene cinnamomifolia (BRONGNIART) UNGER forma *lanceolata* KVAČEK et WALTHER	(+++)
Cercidiphyllum crenatum (UNGER) R.W. BROWN	(+)
Dusembaya seifhennersdorfensis (ENGELHARDT) MAI	(++++)
Nymphaeales fam. et gen. indet.	(+)
Platanus neptuni (ETTINGSHAUSEN) BŮŽEK, HOLÝ et KVAČEK	(+++)
Ulmus fischeri HEER	(+++)
Zelkova zelkovifolia (UNGER) BŮŽEK et KOTLABA	(+)
Celtis pirskenbergensis (KNOBLOCH) WALTHER et KVAČEK	(+)
Celtis (?) bohemica ENGELHARDT	(+)
Quercus lonchitis UNGER	(+++)
cf. *Eotrigonobalanus furcinervis* (ROSSMÄSSLER) WALTHER et KVAČEK	(+)
Betula dryadum BRONGNIART emend. SAPORTA	(+)

Betula alboides ENGELHARDT	(+++)
Alnus gaudinii (HEER) KNOBLOCH et KVAČEK	(+)
Alnus kefersteinii (GÖPPERT) UNGER	(++)
Carpinus cordataeformis MAI	(+)
Carpinus grandis UNGER	(+++)
Carpinus sp.	(++)
Carpinus mediomontana MAI	(+)
Carpinus roscheri WALTHER et KVAČEK	(+++)
Ostrya atlantidis UNGER	(+)
Engelhardtia orsbergensis (WEBER) JÄCHNICHEN, MAI et WALTHER	(+)
Engelhardtia macroptera (BRONGNIART) UNGER	(+)
Cyclocarya sp.	(+++)
Carya cf. *quadrangula* (KIRCHHEIMER) LEROY	(+)
Carya fragiliformis (STERNBERG) KVAČEK et WALTHER	(++++)
Salix varians GÖPPERT	(++)
Populus zaddachii HEER	(++)
Sloanea artocarpites (ETTINGSHAUSEN) KVAČEK et HABLY	(+)
Tilia gigantea ETTINGSHAUSEN	(+)
Craigia bronnii (UNGER) KVAČEK, BŮŽEK et MANCHESTER	(+++)
Dombeyopsis lobata UNGER	(++)
Dombeyopsis sp.	(+)
Hydrangea microcalyx SIEBER	(+)
Rosa lignitum HEER	(++++)
Rosa saxonica (ENGELHARDT) KVAČEK et WALTHER	(+)
cf. *Crataegus* sp.	(+)
Prunus langsdorfii KIRCHHEIMER	(+)
Dicotylophyllum ungeri (ENGELHARDT) KVAČEK et WALTHER	
Acer angustilobum HEER	(++++)
Acer cf. *dasycarpoides* HEER	(+)
Acer engelhardtii WALTHER	(+)
Acer palaeosaccharinum STUR	(++)
Acer rueminianum HEER	(+++)

Acer cf. *tricuspidatum* BRONN	(++)
Acer pseudomonspessulanum UNGER	(+)¨
Acer sp., fructus	(+++)
Nyssa altenburgensis WALTHER et KVAČEK	(++)
Nyssa disseminata (LUDWIG) KIRCHHEIMER	(+)
Ailanthus prescheri WALTHER	(++)
Oleinites hallbaueri (MAI) SACHSE	(+)
Oleinites maii (BŮŽEK, HOLÝ et KVAČEK) SACHSE	(+)
Schefflera dorofeevii MAI	(+)
Ilex tenuiputamenta MAI	(+)
Palaeohosiea suleticensis KVAČEK et BŮŽEK	(+)
Ampelopsis hibschii BŮŽEK, KVAČEK et WALTHER	(+)
Ampelopsis cf. *rotundata* CHANDLER	(+)
Leguminosites pp.	(++)
Toxicodendron herthae (UNGER) KVAČEK et WALTHER	(+)
Diospyros brachysepala A. BRAUN	(+)
Diospyros sp.	(+)
Apocynophyllum neriifolium HEER	(+)
Dicotylophyllum deichmuelleri KVAČEK et WALTHER	(+)
Saportaspermum dieteri KVAČEK et WALTHER	(+)
Saportaspermum cf. *occidentale* MEYER et MANCHESTER	(+)
Potamogeton seifhennersdorfensis ENGELHARDT	(+++)
Potamogeton sp.	(+)
Smilax weberi WESSEL et WEBER	(+)
Spirematospermum wetzleri (HEER) CHANDLER	(+)
Sabal cf. *lamanonis* (BRONGNIART) HEER	(+)
Leersia seifhennersdorfensis WALTHER	(+)
Monocotyledonae gen. et sp. indet.	(++)

Table 6. List of the flora of Hammerunterwiesenthal

Taxon	frequency of specimens
(Frequency categories: 1 - +, 2-to 11 ++, 12 to 50 - +++, more than 50 ++++	
Tetraclinis salicornioides (UNGER) KVAČEK	(+++)
Pinus sp.	(++)
Liriodendron cf. *haueri* ETTINGSHAUSEN (fructus)	(+)
Magnolia sp. (folia)	(++)
Laurophyllum cf. *acutimontanum* MAI	(++)
Laurophyllum cf. *pseudoprinceps* WEYLAND et KILPPER	(++)
Laurophyllum sp. (folia)	(++++)
Daphnogene cinnamomifolia (BRONGNIART) UNGER forma *cinnamomifolia*	(++++)
Daphnogene cinnamomifolia (BRONGNIART) UNGER forma *lanceolata* KVAČEK et WALTHER	(++++)
Daphnogene sp. (folia)	(++++)
cf. *Cercidiphyllum crenatum* (UNGER) R. BROWN	(+)
Ulmus fischeri HEER	(+++)
cf. *Trigonobalanopsis rhamnoides* (ROSSMAESSLER) KVAČEK et WALTHER	(++)
Alnus cf. *rostaniana* SAPORTA	(++)
cf. *Carpinus grandis* HEER	(++)
Engelhardia macroptera (BRONGNIART) UNGER	(+)
Craigia bronnii (UNGER) KVAČEK, BŮZEK et MANCHESTER	(+++)
Hydrangea microcalyx SIEBER	(+)
Acer cf. *integrilobum* WEBER	(+)
Acer cf. *palaeosaccharinum* STUR	(+++)
Acer cf. *tricuspidatum* BRONN	(+)
Acer sp. (fructus)	(++)
Ilex castellii KVAČEK et WALTHER	(++)
Vitis sp. (folia)	(+)
Dicotylophyllum gen. et sp. indet.	(+++)
cf. *Sabal* sp.	(+)
Monocotyledonae gen et sp. indet.	(+++)

Table 7. List of species from Žichov (including the previously published taxa by Sternberg 1820-1838, Ettingshausen 1866, 1868, 1869, and Procházka and Bůžek 1975, revized by Kvaček)

Pinus spp. (= *Pinus taedaeformis* ETTINGSHAUSEN 1866, pl. 13, figs. 13-14)

Tetraclinis salicornioides (UNGER) KVAČEK (= *Libocedrus salicornioides* sensu ETTINGSHAUSEN 1866, pl. 10, figs. 1-4, 6, 7)

Torreya bilinica SAPORTA et MARION (= *Sequoia langsdorfii sensu* ETTINGSHAUSEN 1866, pl. 13, fig. 9)

Liriodendron haueri ETTINGSHAUSEN (1869, pl. 41, fig. 10)

Nymphaea polyrrhiza ETTINGSHAUSEN (1869)

Laurophyllum spp. (= *Laurus fuerstenbergii* ETTINGSHAUSEN 1868, pl. 30, fig. 6)

Daphnogene cinnamomifolia (BRONGNIART) UNGER (= *Cinnamomum scheuchzeri* sensu ETTINGSHAUSEN 1868, pl. 32, figs 2-4, pl. 33, figs. 4, 11, *Cinnamomum polymorphum* sensu ETTINGSHAUSEN 1868, pl. 33, fig. 15, *Cinnamomum spectabile* sensu ETTINGSHAUSEN 1868, pl. 34, figs. 11, 15)

Alnus gaudinii (HEER) KNOBLOCH et KVAČEK (= *Rhamnus gaudinii* sensu ETTINGSHAUSEN 1869, pl. 50, fig. 4)

Alnus kefersteinii (GÖPPERT) UNGER (see ETTINGSHAUSEN 1866, pl. 14, fig. 17-18)

Betula brongniartii ETTINGSHAUSEN sensu ETTINGSHAUSEN 1866, pl. 14, figs. 9-12, ?13)

Carya fragiliformis (STERNBERG) KVAČEK et WALTHER (= *Phylites fragiliformis* STERNBERG, *Carya bilinica* sensu ETTINGSHAUSEN 1869, pl. 52, fig. 3)

Cercidiphyllum crenatum (UNGER) R. BROWN (= *Grewia crenata* sensu ETTINGSHAUSEN 1869)

Leguminosites sp. div. (= *Oxylobium miocaenicum* ETTINGSHAUSEN 1869, pl. 54, fig. 11, pl. 55, figs 3-5, *Dalbergia haeringiana* sensu ETTINGSHAUSEN 1869, pl. 55, fig. 10, *Dalbergia proserpinae* sensu ETTINGHAUSEN 1869, pl. 55, fig. 15, *Sophora bilinica* ETTINGSHAUSEN 1869, pl. 54, fig. 6, *Podogonium knorrii* sensu ETTINGSHAUSEN 1869)

Acer crenatifolium ETTINGSHAUSEN 1869 (= *Acer tricuspidatum* BRONN forma *crenatifolium* (ETTINGSHAUSEN) PROCHÁZKA et BŮŽEK, *Acer trilobatum* sensu ETTINGSHAUSEN 1869, pl. 44, fig. 7, *Acer duplicodentatus* ETTINGSHAUSEN 1869, *Acer dasycarpoides* sensu ETTINGSHAUSEN 1869, pl. 44, figs. 1, 16, *Acer brachyphyllum* ETTINGSHAUSEN 1869, pl. 45, fig. 3)

Sloanea artocarpites (ETTINGSHAUSEN) KVAČEK et HABLY (= *Quercus artocarpites* ETTINGSHAUSEN 1869, pl. 55, fig. 19)

Tilia gigantea ETTINGSHAUSEN (1869, pl. 43, fig. 12) (= *Tilia lignitum* ETTINGSHAUSEN 1869, pl. 42, figs. 3, 6, *Tilia zephyri* ETTINGSHAUSEN 1869, pl. 43, fig. 11)

Ulmus pyramidalis GÖPPERT (*Carpinus pyramidalis* sensu ETTINGSHAUSEN 1866, pl. 15, figs. 5, 7-9)

Zelkova zelkovifolia (UNGER) BŮŽEK et KOTLABA (= *Planera ungeri* sensu ETTINGSHAUSEN 1866)

Smilax weberi WESSEL (*Smilax grandifolia* ETTINGSHAUSEN 1866, pl. 6, fig. 16)

not revized and dubious dicots

Heliotropites reussii ETTINGSHAUSEN 1868, pl. 37, figs. 7-12, 19

Podocarpus eocaenica ETTINGSHAUSEN 1866, pl. 13, fig.1

Myrica bilinica sensu ETTINGSHAUSEN 1866

Carpinus heerii ETTINGSHAUSEN 1866, pl. 15, fig. 10

Corylus insignis sensu ETTINSGHAUSEN 1866

Fagus feroniae sensu ETTINSGHAUSEN 1866

Quercus apollinis ETTINSGHAUSEN 1866

Quercus valdensis ETTINGSHAUSEN 1866, pl. 16, fig. 5

Quercus reussii ETTINGSHAUSEN 1866, pl. 16, fig. 8

Quercus acherontica ETTINGSHAUSEN 1866, pl. 16, fig. 10

Quercus alnoides ETTINGSHAUSEN 1866, pl. 17, fig. 9

Ficus goeppertii ETTINGSHAUSEN 1866, pl. 18, fig. 30

Salix varians sensu ETTINGSHAUSEN 1866, pl. 29, fig. 23

Salix dianae ETTINGSHAUSEN 1866, pl. 29, fig. 20

Pisonia bilinica ETTINGSHAUSEN 1866, pl. 29, figs. 2-4

Laurus styracifolia ETTINGSHAUSEN 1868, pl. 30, fig. 7

Sassafras aesculapi sensu ETTINGSHAUSEN 1868, pl. 31, fig. 9

Viburnum atlantidis ETTINGSHAUSEN 1868, pl. 36, fig. 2

Strychnos europaea ETTINGSHAUSEN 1868, pl. 36, fig. 4

Echitonium superstes ETTINGSHAUSEN 1868, pl. 36, fig. 21

Vitex lobkowitzii ETTINGSHAUSEN 1868, pl. 37, fig. 4

Sapotacites angustifolius ETTINGSHAUSEN 1868, pl. 38, figs. 9-10

Diospyros brachysepala sensu ETTINGSHAUSEN 1868, pl. 39, fig. 1

Diospyros bilinica ETTINGSHAUSEN 1868, pl. 39, figs. 17-18

Styrax stylosa ETTINGSHAUSEN 1868, pl. 39, fig. 12

Styrax vulcanica ETTINGSHAUSEN 1869, pl. 39, fig. 13

Andromeda protogaea sensu ETTINGSHAUSEN 1868, pl. 39, fig. 20

Andromeda acherontis ETTINGSHAUSEN 1868, pl. 39, fig. 7

Cissus atlantica ETTINGSHAUSEN 1869, pl. 40, fig. 5

Belangera obtusifolia ETTINGSHAUSEN 1869, pl. 40, fig. 29

Ranunculus emendatus ETTINGSHAUSEN 1869

Pterospermum ferox ETTINGSHAUSEN 1869

Tetrapteris bilinica ETTINGSHAUSEN 1869, pl. 46, fig. 11

Sapindus haszlinskyi ETTINGSHAUSEN 1869, pl. 43, fig. 13, pl. 47, figs. 1-2

Sapindus cupanoides Ettingshausen 1869, pl. 47, fig. 3

Sapindophyllum dubium Ettingshausen 1869, pl. 46, fig. 21

Aesculus palaeocastanum Ettingshausen 1869, pl. 48, figs. 1-2

Euonymus radobojanus Ettingshausen 1869, pl. 48, fig. 8

Pterocelastrus oreonis Ettingshausen 1869, pl. 48, fig. 20

Rhamnus bilinicus Ettingshausen 1869, pl. 50, fig. 19

Pterocarya denticulata sensu Ettingshausen 1869, pl. 53, figs. 11-15

Callistemophyllum melaleucaeforme Ettingshausen 1869, pl. 54, figs. 2-3

Aronia prisca Ettingshausen 1869, pl. 53, figs. 18-19

Sorbus palaeoaria Ettingshausen 1869, pl. 53, fig. 25

Prinus Olympia Ettingshausen 1869, pl. 53, fig. 21

Swartzia borealis Ettingshausen 1869, pl. 54, figs. 4-5

Quercus haueri Ettingshausen 1869, pl. 55, fig. 18

monocot. indet. (= *Arundo goepperii* Ettingshausen 1866, *Phragmites oeningensis* sensu Ettingshausen 1866, *Sparganium extinctum* Ettingshausen 1866, pl. 7, fig. 8)

trace fossils (*Chondrites bilinicus* Ettingshausen 1866, pl. 1, fig. 9, Hably et al. 2001, pl. 8, fig. 8, *Caulinites dubios* Ettingshausen 1866, pl. 7, figs. 6-7

Table 8. List of the flora of Kleinsaubernitz

Taxon	frequency of specimens
(Frequency categories: 1 - +, 2 to 5 - ++, 6 to 29 - +++, 30 or more - ++++)	
Pronephrium cf. *stiriacum* (UNGER) KNOBLOCH et KVAČEK	(+)
Pinus cf. *palaeostrobus* ETTINGSHAUSEN	(++)
Tsuga sp.	(+)
Cathaya sp.	(+)
Cunninghamia miocenica ETTINGSHAUSEN	(+)
Taiwania cf. *schaeferi* SCHLOEMER-JÄGER	(++)
Sequoia abietina (BRONGNIART) KNOBLOCH	(+++)
Taxodium dubium (STERNGERG) HEER	(++++)
Tetraclinis salicornioides (UNGER) KVAČEK	(++)
Torreya bilinica SAPORTA et MARION	(+)
cf. *Liriodendron haueri* ETTINGSHAUSEN	(+)
Magnolia kvacekii WALTHER	(+)
Laurophyllum acutimontanum MAI	(++)
Laurophyllum pseudoprinceps WEYLAND et KILLPER	(++)
Laurophyllum saxonicum LITKE	(+++)
Laurophyllum sp.	(++)
Daphnogene cinnamomifolia (BRONGNIOART) UNGER forma *cinnamomifolia*	(++)
Daphnogene cinnamomifolia (BRONGNIART) UNGER forma *lanceolata* KVAČEK et WALTHER	(+++)
Kadsura senftenbergensis JÄHNICHEN	(+)
"*Illicium*" *limburgense* KRÄUSEL et WEYLAND	(++++)
Matudaea menzelii WALTHER	(++)
Distylium cf. *heinickei* WALTHER	(+)
cf. *Distylium* sp.	(++)
Platanus neptuni (ETTINGSHAUSEN) BŮŽEK, HOLÝ et KVAČEK	(++)
cf. *Celtis* sp.	(++)
Ulmus fischeri HEER	(++)
Ulmus cf. *pyramidalis* GÖPPERT	(+)
Fagus saxonica KVAČEK et WALTHER	(++)
Quercus cf. *lonchitis* UNGER	(+)

Quercus praekubinyii KVAČEK et WALTHER	(+)
Quercus praerhenana WALTHER et KVAČEK	(++++)
Lithocarpus saxonicus WALTHER et KVAČEK	(++)
Eotrigonobalanus furcinervis (ROSSM.) WALTHER et KVAČEK	
ssp. *haselbachensis* (KVAČEK et WALTHER) KVAČEK et WALTHER	(++++)
Trigonobalanopsis rhamnoides (ROSSMÄSSLER) KVAČEK et WALTHER	(+++)
Quercus bavarica (KNOBLOCH et KVAČEK) KVAČEK	(+)
Alnus phocaeensis SAPORTA	(+++)
Betula kleinsaubernitzensis WALTHER	(+++)
Carpinus grandis UNGER	(++)
Comptonia difformis (STERNBERG) BERRY	(+)
Comptonia cf. *longirostris* JARMOLENKO	(+)
Comptonia sp.	(+)
Myrica lignitum (UNGER) SAPORTA	(+)
Cyclocarya cyclocarpa (SCHLECHTENDAL) KNOBLOCH	(++)
Juglandaceae gen. et sp. indet.	(+)
Salix sp.	(++)
cf. *Populus zaddachii* HEER	(+)
Theaceae gen. et sp. indet.	(+)
"*Viburnum*" *atlanticum* ETTINGSHAUSEN	(+)
Illipophyllum thomsonii KRÄUSEL et WEYLAND	(+)
Ailanthus prescheri WALTHER	(++)
cf. *Cedrela acuminata* (HEER) ILJINSKAYA	(+)
Acer haselbachense WALTHER	(+++)
Acer cf. *tricuspidatum* BRONN	(+++)
Ilex knoblochii WALTHER	(+)
Fraxinus kvacekii WALTHER	(++)
Sloanea artocarpites (ETTINGSHAUSEN) KVAČEK et HABLY	(+)
Dicotylophyllum sp. 1	(+)
Dicotylophyllum sp. 2	(+)
Dicotylophyllum sp. 3	(+)
Dicotylophyllum sp. 4	(+)
Smilax reticulata HEER	(++)
Majanthemophyllum petiolatum WEBER	(++)
Monocotyledonae gen. et sp. indet	(+)