A new Oligocene leaf assemblage from the Ghalandar area (NW Iran) and its contribution to understanding of floristic evolution in the eastern Paratethys

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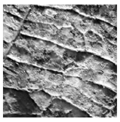

The geological survey in NW Iran (Ahar area, Ghalandar village) carried out by the Czech Geological Survey in the years 2007–2009 provided new data on the geology, coal petrography and palaeobotany of this part of the eastern Paratethys. The recovered plant impressions, dated by radiometric ages of associated volcanic rocks to the Oligocene, have been identified as *Osmunda parschlugiana* (Unger) Andr., *Picea* (sect. *Omorika*) sp., cf. *Magnolia* sp., *Eotrigonobalanus furcinervis* (Rossm.) Walther & Kvaček, cf. *Acer aegopodifolium* (Göpp.) Baik. and *Dicotylophyllum subpeltatum* Kvaček sp. nov. The site characterizes a new floristic assemblage ("complex") Ghalandar in the eastern Paratethys, which differs from the Oligocene broad-leaved evergreen floristic assemblage of Dilizhan previously defined from the Caucasus area by the mixed-mesophytic character of forest vegetation. • Key words: flora, Oligocene, eastern Paratethys, Iran.

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Palaeofloristic evolution in the eastern Paratethys during the Oligocene has long been a focus of interest of Russian palaeobotanists (*e.g*. Kryshtofowicz 1928, Zhilin 1989), because this area, although not explored in detail, brought clues for changes from subtropical towards temperate vegetation types ("Arcto-tertiary hypothesis" of Engler 1879) during the Paleogene. Mai (1995, pp. 312–321) gave a summary of this topic in a detailed analysis including all fossil floras in question. He recognized two main zones playing in their development the most important role: the Tethyan zone and the Boreal zone (Mai 1995, pp. 326–331). For the eastern Paratethys (Caucasus area) he characterized during the Oligocene a single floristic Dilizhan assemblage ("complex") of the broad-leaved evergreen, laurophyllous character, in which evergreen Fagaceae, mainly *Eotrigonobalanus furcinervis* (Rossm.) Walther & Kvaček, dominated (*e.g*. Kolakovsky & Arutjunjan 1969) together with another extinct fagaceous element *Trigonobalanopsis*, legumes and palms (Kasumova 1966; Mai 1995, pp. 412–413). Intriguing questions have arisen when and where this evergreen type of vegetation transitioned to mixed-mesophytic and mostly deciduous forest types occurring in the Oligocene of the adjacent areas in Kazakhstan ("Turgayan" type *sensu* Kryshtofowicz). Sites of Paleogene plant assemblages, which may address these questions, are located either in Kazakhstan or in western Azerbaijan in the territory of the former Soviet Union (Kasumova 1966, Zhilin 1974). None is available beyond these areas.

During the geological survey mapping (in 1:25,000 scale) conducted by the Czech Geological Survey for the Geological Survey of Iran in the years 2007–2009 macrofossil plant remains were encountered in Oligocene ash tuffs near Ghalandar village in the Ahar area, northwestern Iran (Otava *et al*. 2011). During two short visits a small collection of fossil plants was recovered and brought to the Czech Republic for later determination and evaluation. Although limited in its diversity, this flora represents a novelty in the palaeofloristic development of this part of the eastern Paratethys.

Geological setting

The wider area of northwestern Iran with the Alborz and Talesh mountains (Fig. 1) is a part of the collision zone of

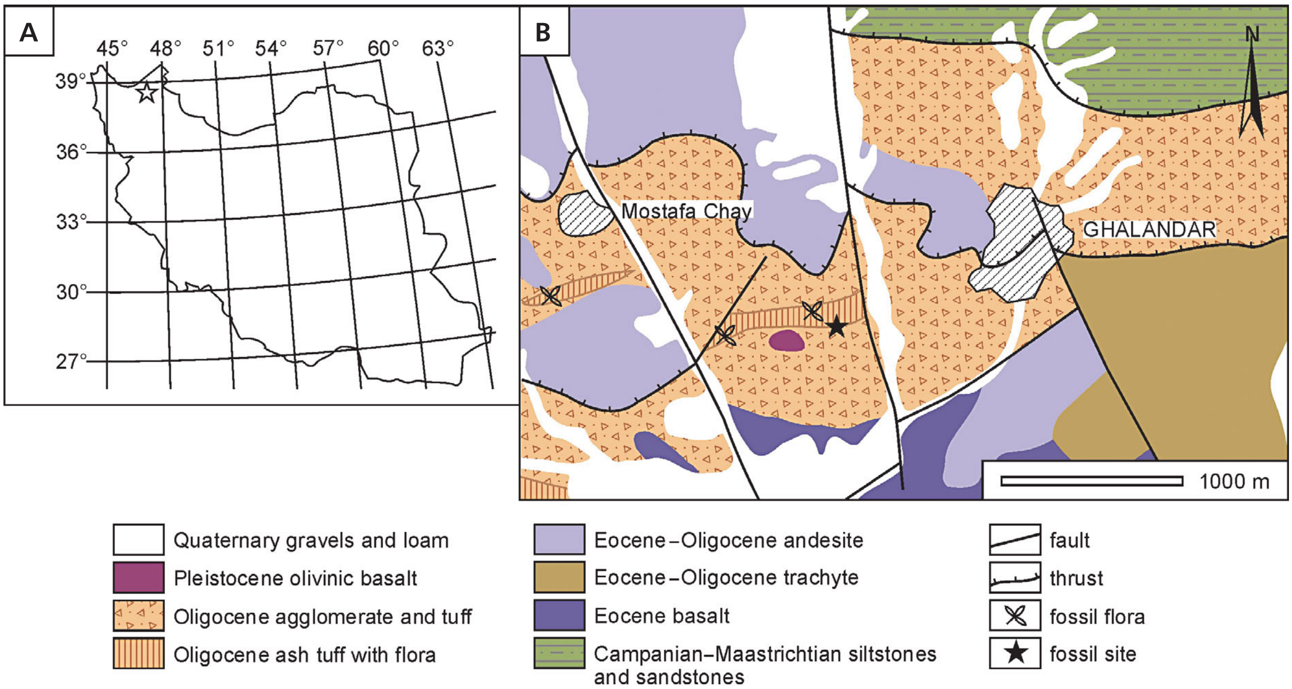


Figure 1. A – position of the fossil site on map of Iran indicated by asterisk. • B – detail geological map of Ghalandar vicinity (after Otava *et al.* 2011, modified).

the Iranian Microplate pushed by the Eurasian Plate to the NE and the Arabian Plate to the SW. This zone is bordered by sutures resulting from the Tethyan arc-arc collision at the NE and by the Tethyan continent-arc collision at the SW (Alavi 1991, Axen *et al.* 2001).

The Alborz and Talesh mountains are built of rocks that originated in the Palaeo-Tethys oceanic realm (Neoproterozoic–Triassic) as well as in the Tethys (Jurassic–Cenozoic) that underwent deformation during the Cimmerian and Alpine orogenies. Metamorphic complexes, sedimentary rocks and magmatic assemblages form either single thrust sheets or complex duplex systems which were transported generally from the NNE to the SSW along numerous thrust faults (Alavi 1996).

According to Lescuyer *et al.* (1978) the Ahar city area (including Ghalandar) is a part of the East Azerbaijan volcanic plateau bordered by the folded zone on the North and by the Mehraban Neogene basin on the South. The East Azerbaijan plateau includes metamorphic complexes of uncertain age, Cenozoic volcanic and plutonic rocks, folded Cretaceous–Paleogene marine sediments and Neogene continental basins.

The immediate surroundings of the Ghalandar city illustrate well the complex geological history of the area. The oldest rocks form a metamorphic complex of unknown age (gneisses, schists and amphibolites). The Upper Cretaceous (Turonian–Maastrichtian) comprises grey rudist limestones, marly limestones with inoceramids, red cherty limestones, grey marlstone flysch and volcano-sedimentary facies with andesitic and basaltic lavas and their volcaniclastics. The Paleocene is represented by oceanic red beds (claystones) and by flysch facies. The Eocene is characteristic by intensive andesitic to basaltic volcanism and volcano-sedimentary facies with hyaloclastites and both coherent and pillow lavas.

Cretaceous to early Oligocene rocks are deformed and overthrusted in the form of nappes as consequence of a major tectonic event around the middle of the Oligocene. The extensive intrusion of monzonites and syenites with a suite of abundant sills and subvolcanic bodies was also related to this event. Products of effusive trachytic and trachydacitic volcanism cover folded older units with angular unconformity. They comprise agglomerate, lapilli and ash tuffs and ignimbrites co-magmatic with the intrusions of plutonic rocks as apparent from complete silicate analyses. K-Ar age of volcanic rocks, obtained during the geological survey in the years 2007–2009 varies around 26 Ma corresponding to an age of Chattian (Otava *et al.* 2011, Rapprich *et al.* 2012).

In the Miocene the Alborz Mountain was uplifted and any Miocene rock record in the wider Ahar area is lacking. During the Pliocene–Pleistocene large intermountain basins filled by continental clastic sediments originated there.

Trachydacitic tuffs from which the plant fossils were recovered are part of the late Oligocene magmatic association. At closer view they can be described as whitish, grey and yellowish fine-grained ash tuffs. Graded bedding, small slump folds and flame structures indicate re-sedimentation of the ash into aquatic conditions. These reworked tuffs possess higher preservation potential for plant macrofossils. Besides leaf and twig impressions, fragments of charcoal as well as pieces of silicified tree trunks were encountered. Fragments of silicified wood reveal the plant-bearing horizon within the tuffs at a distance over 1 km.

In the road cut near the fossil site thin lenses of coal 50 cm in diameter were observed (Fig. 2). The coal can be characterized as inertinite, vitrinite and semifusinite. Organic matter is partly replaced by silica, which fills the cell voids of wood tissue (J. Francŭ, personal communication).

Figure 2. Coal lens enclosed within trachydacitic tuff, Ghalandar village, NW Iran.

Material and method

The fossil plants were collected from a site 800 m west-south-west of the Ghalandar village, north of the Ahar city, NW Iran (N 38° 34´ 28.6˝, E 47° 02´ 49.4˝, 1,650 m above sea level). On the gentle slope fine-grained ash tuffs with plant remains were exposed in flat outcrops and also pieces of silicified tree trunks were observed on the surface (Fig. 3).

The samples studied represent impressions of foliage and twigs preserved in yellow-bedded ash tuff. Due to weathering process some impressions are partly dark brown to reddish, most others represent whitish impressions. Neither remains of leaf substance nor any traces of cuticles were observed on fossils. Hence the identification proceeded on the basis of gross morphological characters preserved.

Figure 3. Silicified tree trunk in the horizon of trachydacitic tuffs near Ghalandar village, NW Iran. Length of trunk is about 2 m.

Systematic palaeobotany

The plant elements, identified and described below, belong to one fern, one conifer, monocots and several broad-leaved dicots. Due to a limited number and fragmentary nature of samples, unambiguous determinations have been only rarely achieved.

Ferns
Family Osmundaceae Martinov

Genus *Osmunda* Linnaeus subg. *Osmunda*

***Osmunda parschlugiana* (Unger) Andreánszky**
Figure 4A, B

Material. – Incomplete pinnule, MB 10b.

Description. – Fragmentary apical part of a pinnule 11 mm wide, incomplete in length (preserved impression 40 mm long), straight narrow ovate, blunt on tip, sub-entire on margin, midrib thin, slender and straight, secondary veins densely spaced (at 0.4–0.8 mm), simple as well as once or twice forked near the midrib or rarely again slightly higher, at an angle of *ca* 50–40° (–30° near pinnule tip).

Remarks. – This fern was probably mentioned (without illustrations) in the Oligocene plant assemblages of the adjacent region of the Lesser Caucasus (Kasumova 1966, p. 6) under various names, *e.g*. *Pteris parschlugiana* Unger, *Pteris pennaeformis* Heer, *Osmunda heerii* Gaudin, but we were unable to verify the identifications by inspection of the collected specimens. Similar foliage remains are known also in the Oligocene of Kazakhstan, *e.g*. at Ashutas (Kryshtofowicz *et al.* 1956, p. 45, pl. 1, figs 1, 2, text-fig. 5a–ž, as *Osmunda doroshiana* Göpp.), Bukhtarma (Rajushkina 1979, p. 52, pl. 15, fig. 6, as *Osmunda heerii*

Gaudin) and elsewhere associated with the Turgayan ("Arcto-tertiary") leaf assemblages. Although sterile and fragmentary, the affinity of the above described single impression to *Osmunda* subg. *Osmunda* is evident.

Records assigned to different fossil species of *Osmunda* subg. *Osmunda* from the early Paleogene, *e.g. O. sachalinensis* Krysht. (Paleogene of eastern Asia – Borsuk 1956, Tanai 1970), *O. macrophylla* Penhallow (Paleogene of the Arctic – Boulter & Kvaček 1989, Budantsev & Golovneva 2009) do not differ essentially and conform the venation pattern of recent *O. regalis* Linnaeus. Occurrences of *Osmunda parschlugiana* are spread in Europe in wetland vegetation of many Miocene sites (Hably 2013) and rarely cross the Oligocene–Miocene boundary avoiding plant assemblages of warm climatic zones called the mastioixoid floras.

Conifers
Pinaceae Lindl.

***Picea* A. Dietr. sect. *Omorika* Willk.**

***Picea* sp.**
Figure 4C–E

Material. – Twigs and needles, MB 1 to 4.

Description. – Twigs widely alternately ramified, up to 3 mm thick, densely covered by distinct helically disposed peg-like rhomboid cushions (pulvini), mostly devoid of needles, exceptionally with solitary needles attached, detached needles dispersed close to twigs, needles truncate at base, acute at apex, flat, 1–1.6 mm wide, slightly more than 20 mm long.

Remarks. – This conifer matches in the sculpturing of twigs the pattern, which is very characteristic of spruce, particularly well-developed pulvini, which help to distinguish *Picea* from other genera of the Pinaceae (LePage 2001). Our collection corresponds in the morphology of dorsiventrally flattened needles to *Picea* sect. *Omorika*. Neither other organs nor details of leaf anatomy have been recovered associated.

Fossil macrofossils of spruce have been described from the Oligocene of Kazakhstan (*Picea altaica* Rajushkina, *Picea mugodzharica* Rajushkina, *Picea* sp. – Rajushkina 1968, 1979). Contrary to the above-described fossils, these records are related to sect. *Picea* and show the quadrangular cross section of needles. The available material does not preserve necessary details of sterile twigs to be compared with all other fossil representatives of spruce based on foliage (for the review see LePage 2001).

Angiosperms
Family Magnoliaceae Juss.

Genus *Magnolia* L.

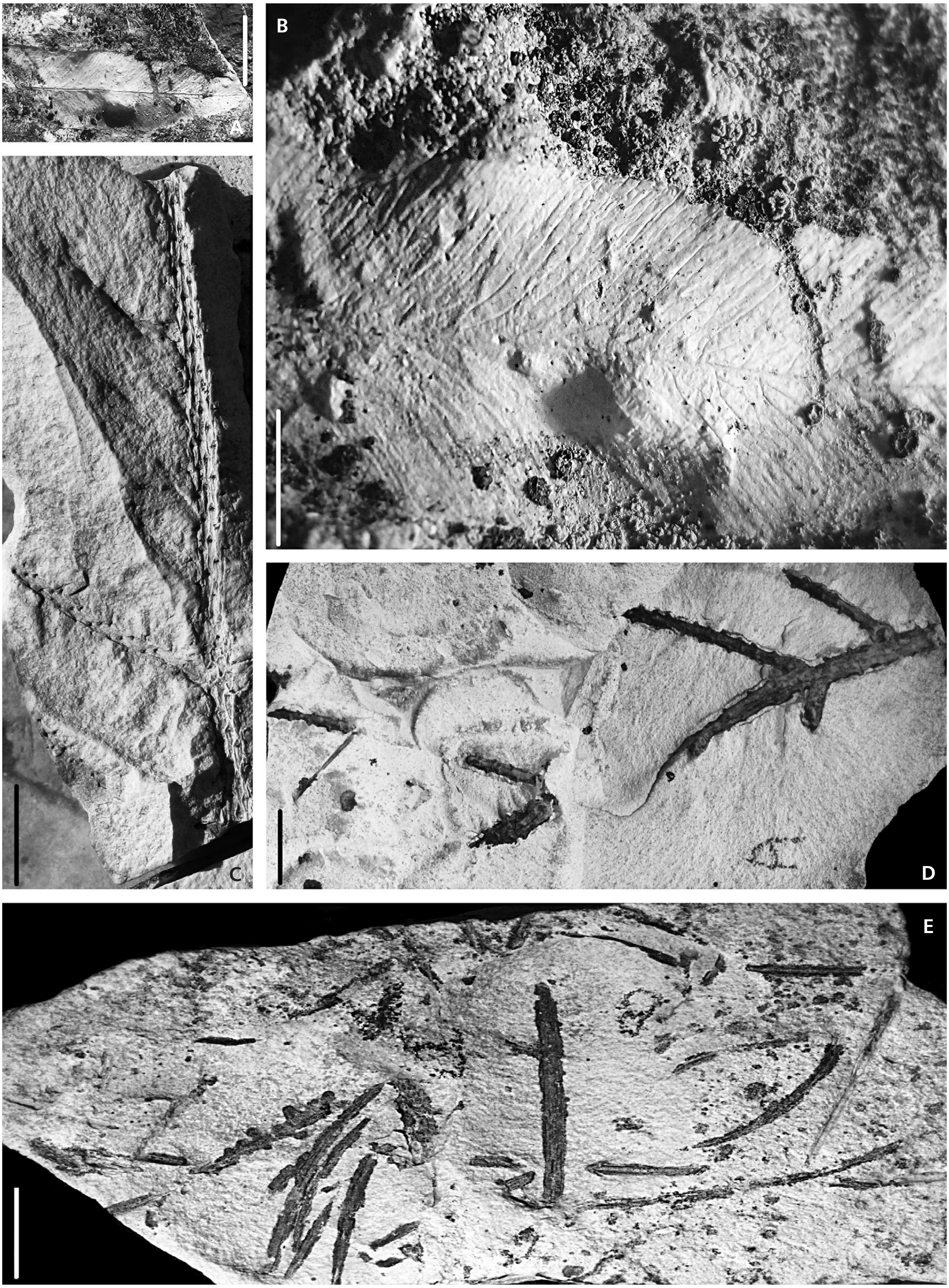
cf. *Magnolia* sp.
Figure 5A–C

Material. – Leaf impression and counter-impression, MB 6a, b.

Description. – The lower part of a large oblong leaf more than 60 mm wide and much over 120 mm long, base entire-margined, narrow rounded and at very base truncate to shallowly sub-cordate, venation brochidodromous, midrib straight, medium thick, secondary veins at base denser, almost perpendicular to the midrib, higher secondary veins mostly regularly spaced and dense, almost straight, simple, at angles of *ca* 40° slightly increasing proximally, forked and looping close to margin; intersecondaries absent, tertiary venation vaguely visible, sinuate, forked.

Remarks. – Similar large leaves with the entire margin and dense regular secondary venation are not common in the fossil state. Some were recognized as magnolias, *e.g. Magnolia schaarschmidtii* Walther, 2003 in the Eocene of the Weisselster Basin, Germany or *M. maii* Walther, 2003 in the Oligocene of Saxony, both with the preserved epidermal anatomy. They both differ from the above-described specimen in the broader leaf form and *M. maii* by the distinctly cordate base. A definite determination of the leaf would require epidermal characteristics. Impressions of this sort may also be produced by Lauraceae and Fagaceae [*e.g. Eotrigonobalanus furcinervis* (Rossm.) Walther & Kvaček – see below]. Several living magnolias with deciduous foliage produce leaves similar to the above-described fossil, mainly of sect. *Buergeria* (Sieber & Zucc.) Baill., *e.g. M. salicifolia* (Sieber & Zucc.) Maxim. distributed in Japan.

Figure 4. A, B – *Osmunda parschlugiana* (Unger) Andreánszky. • A – fragmentary pinnule, MB 10b, scale bar = 10 mm. • B – magnified detail of the previous figure showing venation, scale bar = 5 mm. • C–E – *Picea* sp. • C – twig without needles, MB 1, scale bar = 10 mm. • D – twig with an attached needle, MB 3A, scale bar = 10 mm. • E – dispersed fragmentary twigs and detached needles, MB 3B, scale bar = 10 mm.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Family Cyperaceae Juss.

Genus *Cyperacites* Schimper

***Cyperacites* sp.**
Figure 5C

Material. – Leaf impressions, MB 10c, others not catalogued.

Description. – Fragments of linear leaves, 2–4 mm wide, slightly revolute at margin and with a medial shallow grove; fine parallel venation obscured by fossilization.

Note. – Such narrow monocotyledonous leaves preserved as leaf impression material are not determinable to the natural system of monocots and, nomenclaturally, are usually treated only as form taxa. Schimper (1870–1872) correctly replaced the name of the fossil genus *Cyperites* Lindley & Hutton (based on foliage of *Sigillaria*) by *Cyperacites* Schimper, formally typified by *C. dubius* (Heer) Schimper (see Andrews 1970, p. 67). This fossil taxon requires a wider study. The above-described fragments correspond to several fossil species listed in Schimper (1870–1872) and described by Heer (1855, p. 79, pl. 29, fig. 3 – Lausanne; Heer 1869, p. 28, pl. 3, figs 15b, 17, pl. 12, fig. 17 – Svetlogorsk *etc*.) from the Paleogene deposits of Europe. The affinity of the fragments at hand to living monocotyledons is obvious but determination of a more exact systematic position is out of question.

Family Fagaceae Dum.

Genus *Eotrigonobalanus* Walther & Kvaček

***Eotrigonobalanus furcinervis* (Rossm.) Walther & Kvaček**
Figures 6A, B

Material. – Leaf impression and counter-impression, MB 5.

Description. – Leaf elliptic, incomplete, 30 mm wide, more than 60 mm long, simple dentate, base rounded, slightly asymmetrical, apex missing, venation semicraspedodromous, midrib straight, thick secondary veins mostly regularly spaced, at an angle of *ca* 45° slightly increasing proximally, forked in the second third of the length or slightly closer to the margin, tertiary venation not visible.

Remarks. – Leaves of *Eotrigonobalanus* are the most characteristic angiosperm foliage at numerous European late Paleogene sites (see Mai & Walther 1985, as *Dryophyllum furcinerve*, Kvaček & Walther 1989). The leaves vary considerably from entire-margined to coarsely dentate and show a characteristic epidermal anatomy. This plant element is common in the Oligocene plant assemblages of the Caucasus and adjacent areas [Kasumova 1966 – as *Quercus furcinervis* (Rossm.) Unger, *Q. vetusta* Kassumova, *Q. talyschensis* Kassumova; Kolakovsky & Arutjunjan 1969 – designated as *Castanopsis furcinervis* (Rossm.) Kräusel & Weyland].

Family Sapindaceae Juss.

Genus *Acer* L.

cf. *Acer aegopodifolium* (Göpp.) Iljinskaja
Figure 6C, D

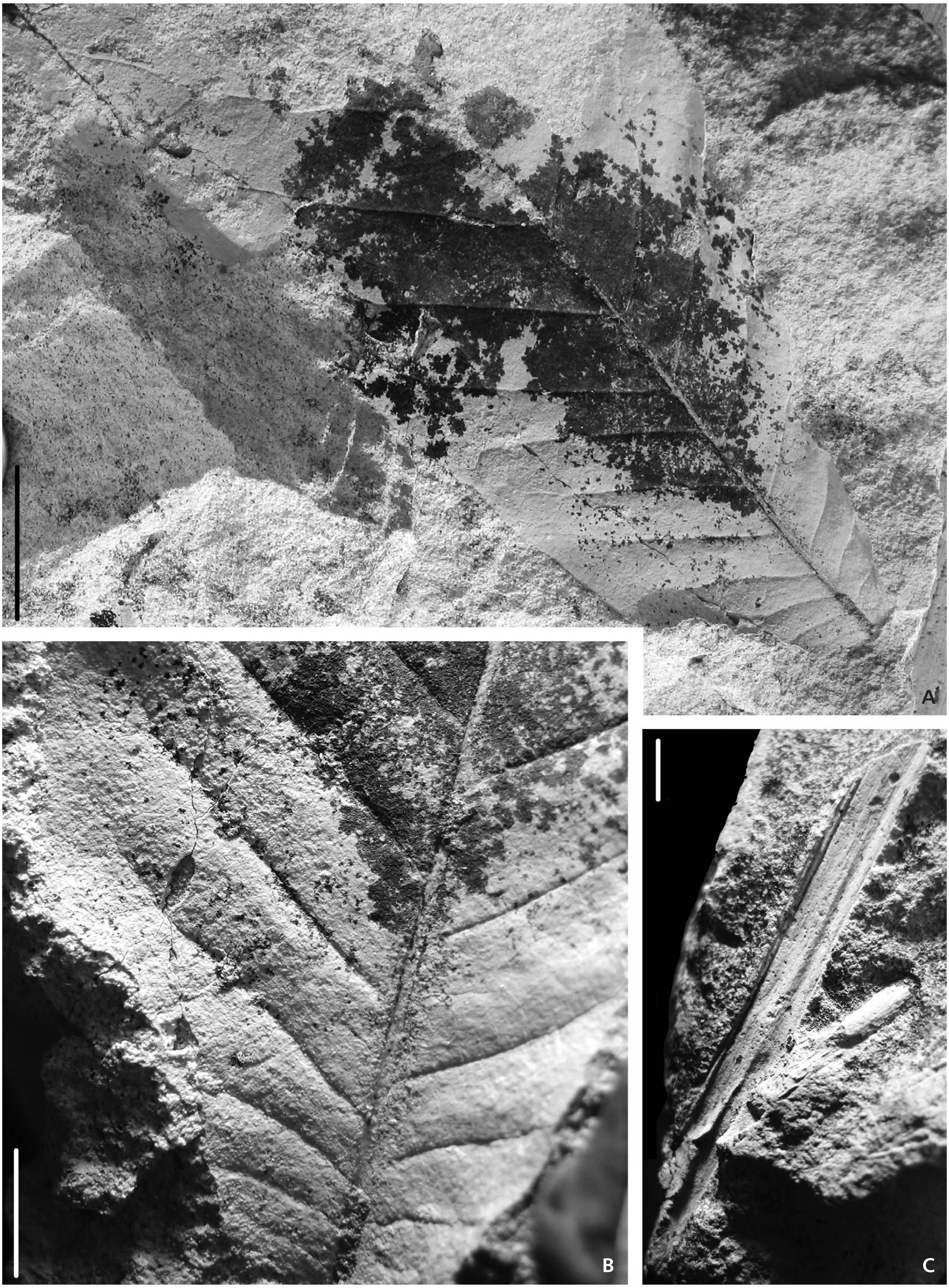
Material. – Leaf fragment, MB 10a.

Description. – An incomplete fragment of lobate or compound leaf with only one lobe (leaflet?) preserved, lamina coarsely bluntly dentate, 15 mm wide, 30 mm long, apex acuminate, base missing, venation craspedodromous, slightly asymmetrical, midrib slightly S-shaped, secondary veins irregularly widely spaced, bent towards apex, at an angle of about 40° or less, partly forked, reaching the tooth apex. Tertiary vein fabric irregular reticulate, epimedial tertiary veins almost perpendicular to slightly acute to the midrib. Higher-order venation obscure.

Remarks. – The described fossil leaf fragment is very incomplete and the determination must remain doubtful. The asymmetrical base and rounded as well as triangular teeth on margin correspond well with the morphology of leaflets of *Acer aegopodifolium* as illustrated from the Upper Oligocene–Lower Miocene of Ustjurt (Zhilin 1974, pl. 40, figs 5–7).

This maple probably immigrated from Asia to Europe later during the Miocene. These new fossils have been suitable to verify the systematic position by epidermal anatomy (see Schmitt & Kvaček 1999, Walther & Zastawniak 2005). On account of detailed venation, Kovar-Eder (1988)

Figure 5. cf. *Magnolia* sp. • A – fragmentary leaf, MB 6A, scale bar 20 mm. • B – magnified basal part of the previous figure, scale bar 10 mm. *Cyperacites* sp. • C – leaf fragment, MB 10C, scale bar = 5 mm.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recognized the affinity of *Acer aegopodifolium* to sect. *Trifoliata*.

Angiosperms fam. inc.

Genus *Dicotylophyllum* Saporta

***Dicotylophyllum subpeltatum* sp. nov.**
Figure 6E–H

Holotype. – Leaf impression, MB 8a (Fig. 6E), coll. Czech Geological Survey, Praha.

Paratypes. – Leaf impressions, MB 8b, c, MB 9 (Fig. 6F, H), coll. Czech Geological Survey, Praha.

Etymology. – According to the leaf base.

Description. – Leaves simple and entire-margined (?), incomplete (without apices), lamina at base more than 60 mm wide, widely rounded, sub-peltate, venation palmate, primary vein framework basal, midrib straight, lateral primary veins 2 on either side, radiating from the base at an angle of 40 to 45°, apically slightly bent, secondary veins eucamptodromous, parallel, widely spaced, tertiary veins very distinct, intercostal percurrent alternate, epimedial mixed percurrent, higher-order venation reticulate, areoles *ca* 0.3 mm in diameter, free ending veinlets absent.

Remarks. – The available material is very incomplete. The surface of one slab shows several large leaf impressions, which are partly overlapping in a manner recalling foliage of an aquatic plant floating on the water surface. This accumulation may have arisen accidentally in sedimentation of low energy in standing water. None of the leaf specimens is completely preserved as a whole leaf and all lack petiole. A very distinctive tertiary venation allows recognizing individual even fragmentary specimens of the same fossil species.

Similar leaf morphotypes have been assigned to *Populus* L., *e.g. P. jarmolenkoi* (Iljinskaja) Iljinskaja from the late Oligocene flora of Ashutas, *P. parapacifica* Chelebaeva from the Oligocene and Neogene of the Far East – see Iljinskaja *in* Arbuzova *et al*. (2005) or *P. germanica* (Menzel) Walther *in* Mai & Walther (1978) from the Oligocene of Germany. They all differ from *D. subpeltatum* in the petiolate leaf base with a flattened petiole and partly toothed margin. The distinct venation preserved in tuff on an unevenly spread lamina agrees with a presumed soft texture and deciduous character of foliage. We meet similar difficulties in assessing systematic affinities as in the case of *D. semipeltatum* (Rossm.) Knobloch & Kvaček from the late Eocene Staré Sedlo flora of north Bohemia (Knobloch *et al.* 1996). Foliage with similar venation patterns was reported from the Eocene of Europe (Messel, Kučlín, Lábatlan) as *Byttneriopsis* Kvaček & Wilde, 2010, and interpreted on account of epidermal anatomy and co-occurrence of seeds as fossil malvalean plants.

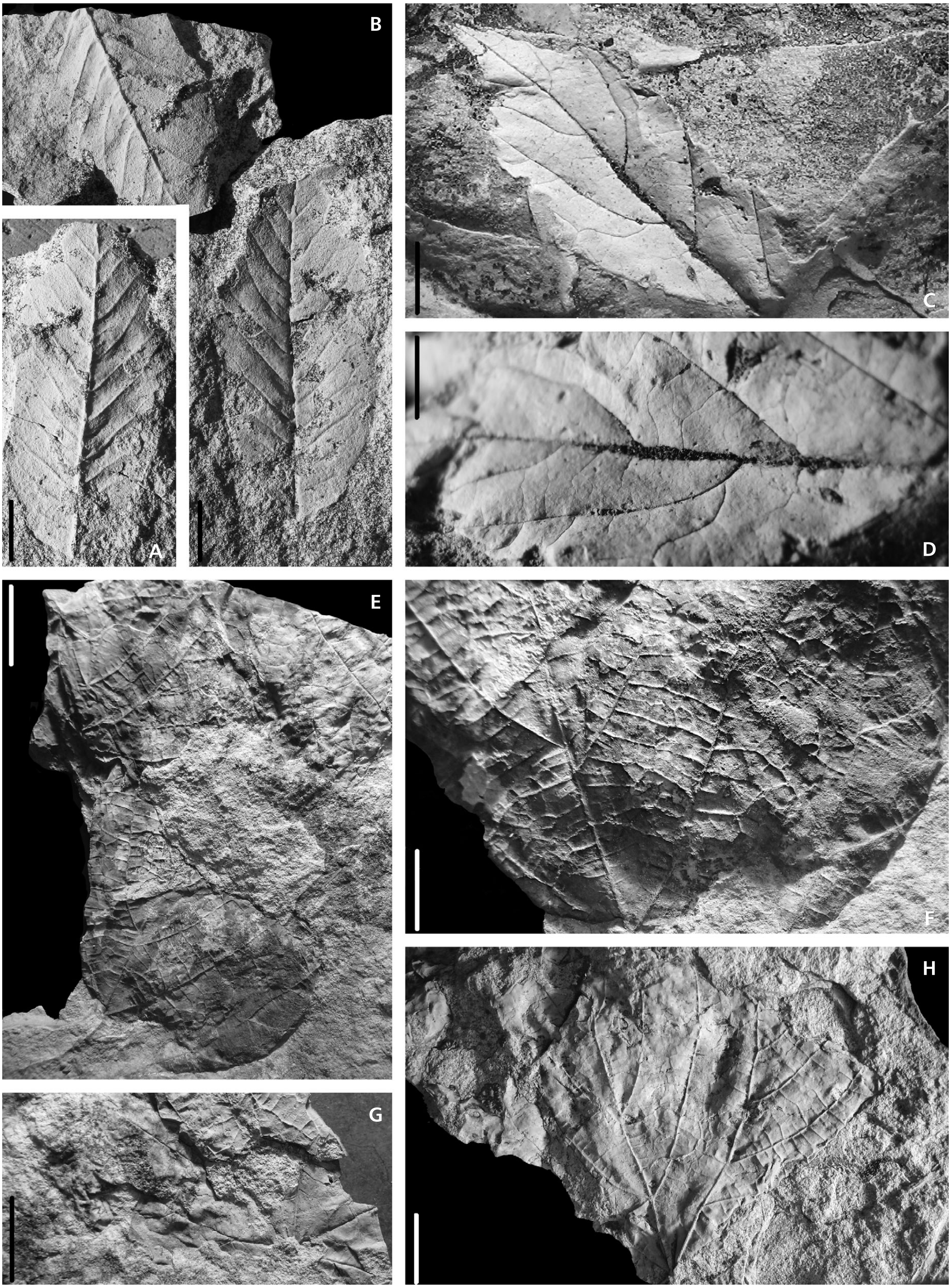
Palaeoenvironment

The late Oligocene plant assemblage of Ghalandar suggests existence of a forested area, in which broad-leaved trees prevailed. Due to equable representation of both evergreen and deciduous elements, the reconstructed vegetation cover corresponds to the mixed mesophytic forest type. We are unable to support our judgment by a statistical calculation because diversity of the plant assemblage is too low. The proximity of lignite layers indicates humid palaeoclimatic conditions with a moderate annual precipitation without a pronounced dry season. In general, the Ghalandar plant assemblage supports the palaeoclimatic estimations suggested by Akhmetiev (Akhmetiev & Zaporozhets 1992, Akhmetiev *in* Popov *et al.* 2009) for the northern Caucasus and Kazakhstan, *i.e.* Mean Annual Temperature 13–20 °C and Annual Precipitations to 1000 mm.

Relations to other Paleogene plant assemblages in the eastern Paratethys

The collected plant material from Ghalandar consists of only a limited number of elements, which clearly differentiate this plant assemblage from the others recovered so far in the eastern Paratethys Oligocene. It belongs to a new floristic complex that differs from the previously defined one of Dilizhan (*sensu* Mai 1995, p. 412) in the Oligocene of the Caucasus area by the mixed-mesophytic ("Arcto-tertiary" or Turgay) character. This new floristic assemblage ("complex") of Ghalandar includes macrofossils of

Figure 6. A, B – *Eotrigonobalanus furcinervis* (Rossm.) Walther & Kvaček. • A – fragmentary leaf, MB 5A, scale bar = 10 mm. • B – counter-impression of the previous figure with a fragment of leaf shown in Fig. A, MB 5B&A, scale bar 10 mm. • C, D – cf. *Acer aegopodifolium* (Göpp.) Iljinskaja. • C – leaf fragment, MB 10A, scale bar = 10 mm. • D – detail of the previous figure, scale bar = 5 mm. • E–H – *Dicotylophyllum subpeltatum* Kvaček sp. nov. • E – a group of leaf impressions with the holotype (below), MB 8, scale bar = 20 mm. • F – detail of holotype, MB 8A, scale bar = 10 mm. • G – subpeltate leaf base, MB 7, scale bar = 10 mm. • H – leaf fragment with indistinctly dentate (?) margin, MB 9, scale bar = 10 mm.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Osmunda subg. *Osmunda*, *Picea* and broad-leaved dicotyledonous elements, partly deciduous (*Acer* and probably *Magnolia*), partly evergreen (*Eotrigonobalanus*). In this respect it resembles much richer plant assemblages in the Zaisan area, such as Ashutas (Kryshtofowicz *et al*. 1956), or in the Altai Mts (Rajushkina 1979) while those from the western Azerbaijan (Kasumova 1966, Kolakovsky & Arutjunjan 1969) are dominated by evergreen Fagaceae, mainly *Eotrigonobalanus* and *Trigonobalanopsis,* and Lauraceae. The previously overlooked occurrence of *Doliostrobus* (Kasumova 1966, pl. 11, fig. 11, as *Cypressus* sp.) connects the Indzhachai flora with the European Eocene and early Oligocene. The Ghalandar floristic assemblage fits in the Turgay (Kazakhstan) province, as characterized by Akhmetiev (*in* Popov *et al.* 2009, p. 107), connected with the warm temperate forest types described from Ustjurt, northern Pri-Araľye and Turgay (see Zhilin 1974, 1989). Our findings support the stepwise immigration of the so-called Turgay (Zhilin 1989) or "modern Arcto-tertiary" elements (Kvaček 1994) from Asia to Europe during the Paleogene.

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