Aspects of Romanian Early-Middle Jurassic palaeobotany and palynology. Part VII. Successions and floras.

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Aspects of Romanian Early-Middle Jurassic palaeobotany and palynology. Part VII. Successions and floras*

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Abstract The Jurassic floras of Romania occur in the Carpathian Mountains and in Dobrogea (Eastern Romania). In the South Carpathians, diverse and well preserved floras have been recorded since the middle of the 19th Century in the Resita, Sirinia, Presacina, Cerna-Jiu, Holbav and Cristian Basins. The ages of these floras range between Hettangian and Sinemurian, with representatives belonging to Bryophytes, Pteridophytes and Gymnosperms. Excellent preservation and diversity were recorded in Anina, in the central area of the Resita Basin, a possible fossile-Lagerstätte locality. The 3D collecting opportunities due to underground mining for coals permitted detailed phytostratigraphical studies. These studies showed a floral change at the Hettangian-Sinemurian boundary, related to climate change. The Jurassic coal basins of the South Carpathians show both intramontain and paralic features. The Resita Basin is a typical intramountainous depression basin, while the other basins are influenced by the marine realm. From a paleogeographical point of view, the Romanian Early and Middle Jurassic floras occurred on the northern frame of the Tethys realm, floristic features indicating the Eurosinian Province. One of the closest floras in terms of floristic similarities is the Iranian Early Jurassic flora. In the Apuseni Mountains, the Hettangian-Sinemurian flora is less preserved and diverse than those of the South Carpathians. The Middle Jurassic flora of Romania is confined to Dobrogea (Eastern Romania), where a bennettite-dominated assemblage with low diversity and preservation was recorded.

Keywords: Hettangian-Sinemurian, Middle Jurassic, macroflora, phytostratigraphy, paleoecology, paleogeography.

The Jurassic system in Romania is well represented in both Carpathians and in their foreland[1,2]. The Jurassic continental deposits are confined to the South Carpathians and to the Apuseni Mountains, and their age is consistently Early Jurassic, generally Hettangian-Sinemurian[3—5].

The South Carpathians (Fig. 1) consist in a series of nappes, overthrusted from West towards East, in the following order: the Supragetic Nappe, the Getic Nappe, the Severin Nappe, and the Danubian structural units, the latter being autochthonous. Of these units, only the Getic Nappe and the Danubian units yield Jurassic continental deposits.

In the Apuseni Mountains, the Bihor unit includes continental deposits with fossil plants as well, belonging to a different paleogeographic setting to those of the South Carpathians.

Popa provided a general overview of the Romanian Jurassic floras[3], with emphasis on their systematics and paleoecology, the present paper expanding the previous synthesis.

The following basins include Lower Jurassic continental deposits: the Resita, Hateg, Holbav and Cristian Basins of the Getic Nappe, the Sirinia, Presacina, and Cerna-Jiu, Basins of the Danubian units, in the South Carpathians, and the Suncuius Basin in the Apuseni Mountains. The geology and the paleofloras of these basins are outlined in the following sections.

1 The Resita Basin (Getic Nappe)

The Resita Basin (Fig. 2) is the largest sedimentary basin of the Getic Nappe, including both a Paleozoic and a Mesozoic cycle, unconformably overlying the crystalline basement. The Lower Jurassic continental deposits are assigned to the Steierdorf Formation[6,7], and include three members: Dealul Budinic, Valea Tereziei and Uteris members. The Dealul Budinic Member (lowermost Hettangian) is a basal sequence, coarse, conglomeratic, sometimes of reworked Permian red beds, conformably overlain by the fine coal measure represented by the Valea Tereziei Member (Hettangian-Sinemurian). The conformable successions (Valea Tereziei Member) in-

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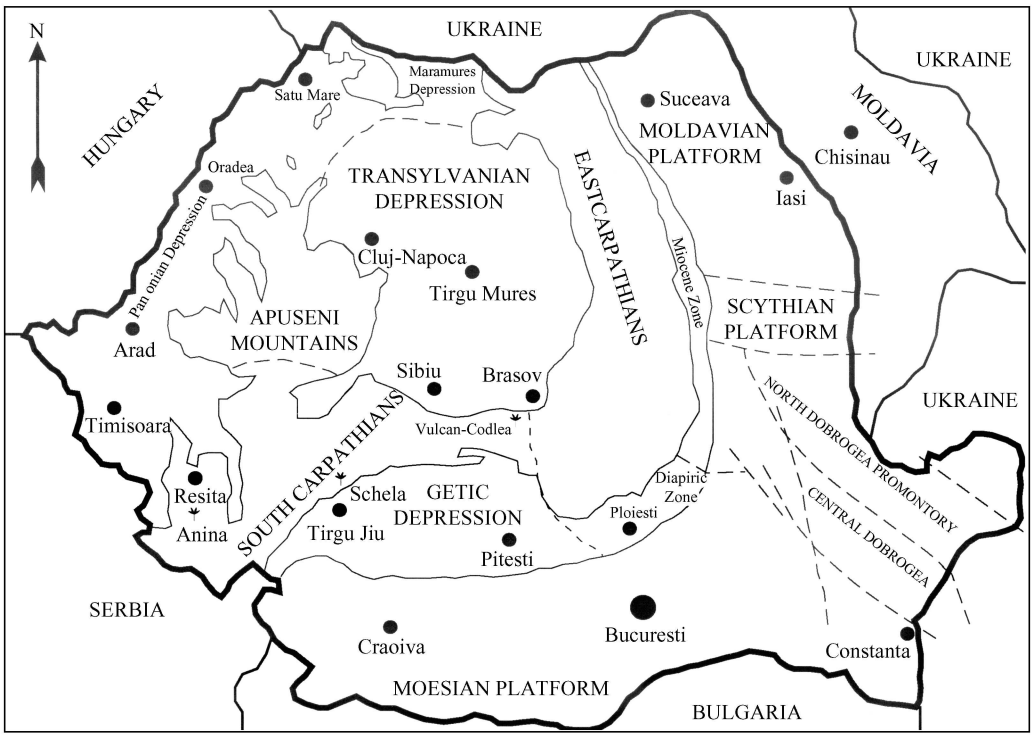

Fig. 1. Simplified geological map of Romania, with the most important Early Jurassic plant-bearing localities in the South Carpathians (Anina, Schela, and Holbav).

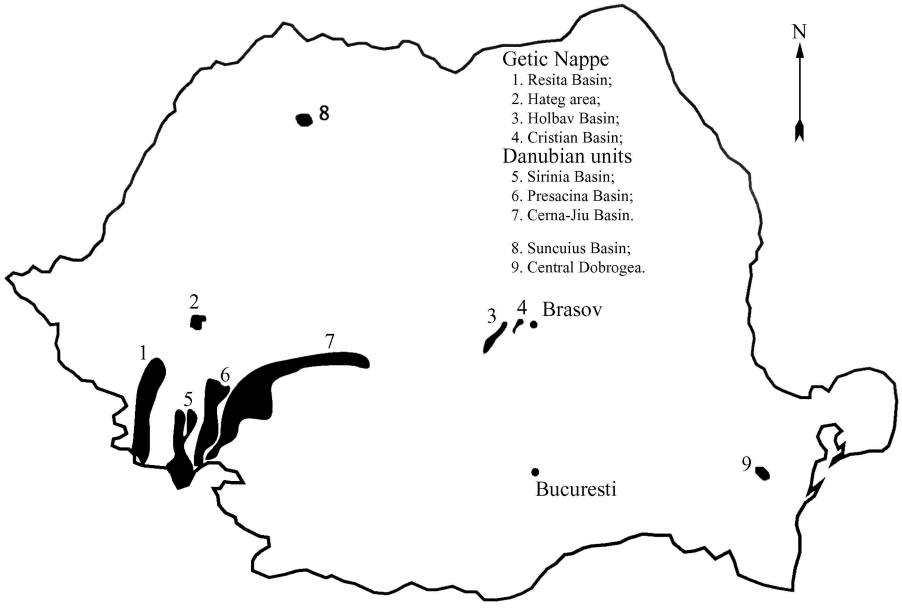

Fig. 2. Sedimentary basins yielding Jurassic continental formations in Romania.

clude sandstones, mudstones, and coals, assigned to several lateral, interlayering facies. The central Anina facies yields 8 coal seams, still extracted today since 1792. Other important contemporaneous facies are the Bradet facies, and the Doman facies, both of them with coals. The Uteris Member (Pliensbachian-Middle Toarcian), is represented by black, bituminous shales, very probably linked to a global anoxic event. The main unit should probably be distinguished as a separate formation, and not included in the Steierdorf Formation. These Lower Jurassic sediments are conformably overlain by Middle Jurassic marls, which are very rich in marine invertebrates, are assigned to the Tilva Zinei Formation[6,7].

Important Early Jurassic plant localities within the Resita Basin include Anina (formerly known as Steierdorf), represented by several exposures, mining pits, open cast mines, and Doman (Table 1). Less important localities are Predilcova, Padina Matei and Beu Sec.

Table 1. The main localities with Early Jurassic plants in Romania

Unit	Basin	Locality name	Geographic region
Getic Nappe	Resita Basin	Anina (cluster)	Anina Mountains
		Beu Sec	
		Doman	
		Padina Matei	
		Predilcova	
	Holbav Basin	Holbav	Brasov Hills
		Concordia	
		Victoria	
	Cristian Basin	Cristian (cluster)	
	Hateg Basin	Pui	Hateg
Upper Danubian	Sirinia Basin	Berzauca	Almaj Mounains
		Bigar (cluster)	
		Buschmann	
		Camenita	
		Chiacovat	
		Cozla	
		Rudaria	
		Dragosella East	
		Dragosella Mica	
		Dragosella West	
		Jeliseva	
		Pietrele Albe	
		Pregheda	
		Speranta	
		Stanca	
		Ostresu	
Lower Danubian	Presacina Basin	Mehadia	Mehedinti
		Baia de Arama(cluster)	
Lower Danubian	Cerna Basin	Cerna Virf	
		Crasna	
		Novaci	
		Obirsia Closani	
		Schela	Oltenia
		Tismana	
Bihor Unit	Suncuius Basin	Suncuius (cluster)	Bihor Mountains

Anina, with its underground mining horizons (Pit No. 1 is the deepest in Europe), and open cast mines, permits three dimensional opportunities for fossil plant collecting, with stratigraphic and lateral control of the collected paleobotanical material. These opportunities are unique in Europe and permit high resolution stratigraphic and paleoecological studies[4,5,8].

The Anina, Bradet and Doman facies are the richest plant bearing continental sequences of the whole basin. The Anina flora was first described by Foetterle[9], followed by Ettingshausen[10], and Andrae[11], and subsequent contributions were provided by Krasser[12,13], Semaka[14,15], Humml[16,17], and Givulescu[18], Popa[4]. Other authors dealing with the Resita Basin flora were Stur[19], Staub[20], Thomas[21], Langer[22], Czier[23], Popa[3], alongside with Givulescu[24—29], Givulescu and Farcasiu[30], Givulescu and Popa[31], Popa[8,32], and Popa and Van Konijnenburg-Van Cittert[33]. These contributions focus on one or several taxa, as detailed structural and taxonomical studies.

The Hettangian-Sinemurian of the Resita Basin hosts a compression flora, with the highest preservation in Romania. Cuticles and in situ pollen and spores are commonly preserved[3,4,33]. The flora from Anina is particularly diverse, with exceptionally preserved compressions, occurring in the central area of the Resita Basin.

The flora of the Resita Basin counts more than 120 species of Early Jurassic plants. Gymnosperms are particularly diverse in the Resita Basin, whereas pteridophytes are subordinated. Bryophytes are rarely recorded in the Early Jurassic assemblages, however *Hepaticites* cf. *arcuatus* was recorded from Ponor Quarry, in Anina[4].

Lycopids, such as Isoetales are represented by *Isoetites* sp., another rare record for the Early Jurassic flora of Romania. Sphenophytes are frequent, with species of *Equisetites* and *Schizoneura* (*S. carcinoides*), an important coal forming plant. *S. carcinoides* is also a species spanning the Hettangian-Sinemurian boundary, due to its paleoecological status, as a swamp dweller. *S. carcinoides* is a ubiquitous species in the former swamp areas of the Resita Basin, this habitat permitting it to survive climate changes and to generate substantial vegetal mass for coal genesis.

Ferns are abundant. Marattialean ferns include *Marattia* (*M. intermedia*, *M. barnardii*), while the Filicales count representatives of Osmundaceae (e. g. *Osmundopsis sturii*), Matoniaceae (*Phlebopteris woodwardii*, *Aninopteris formosa*, *Matonia braunii*), Dipteridaceae (*Thaumatopteris brauniana*, *Dictyophyllum irregularis*, *D. nilssonii*, *Hausmannia buchii*, *H.* cf. *dentata*), Dicksoniaceae (*Coniopteris murrayana*, *Kylikipteris*

arguta) and Incertae sedis (species of *Cladophlebis*, such as *C. dentata*, *C. nebbensis*, and others). *Thaumatopteris brauniana* (including here material which can be assigned to *T. schenkii*, a junior synonym of *T. brauniana*) is a very useful marker for the Hettangian in the Resita Basin (Fig. 3, Refs. [3—5]). Osmundaceous ferns such as *Osmundopsis sturii* (with associated foliage assigned to *Cladophlebis denticulata*) were opportunistic plants that were important contributors to peat deposits commonly co-occurring with some bennettites, such as *Zamites schmiedelii*. In situ "trunks" of *Cladophlebis denticulata* were recorded in the Ponor Quarry, in Anina, covering a paleosol structural surface in vertical position, in a rare situation of an outcrop showing such exquisite preservation of paleob-

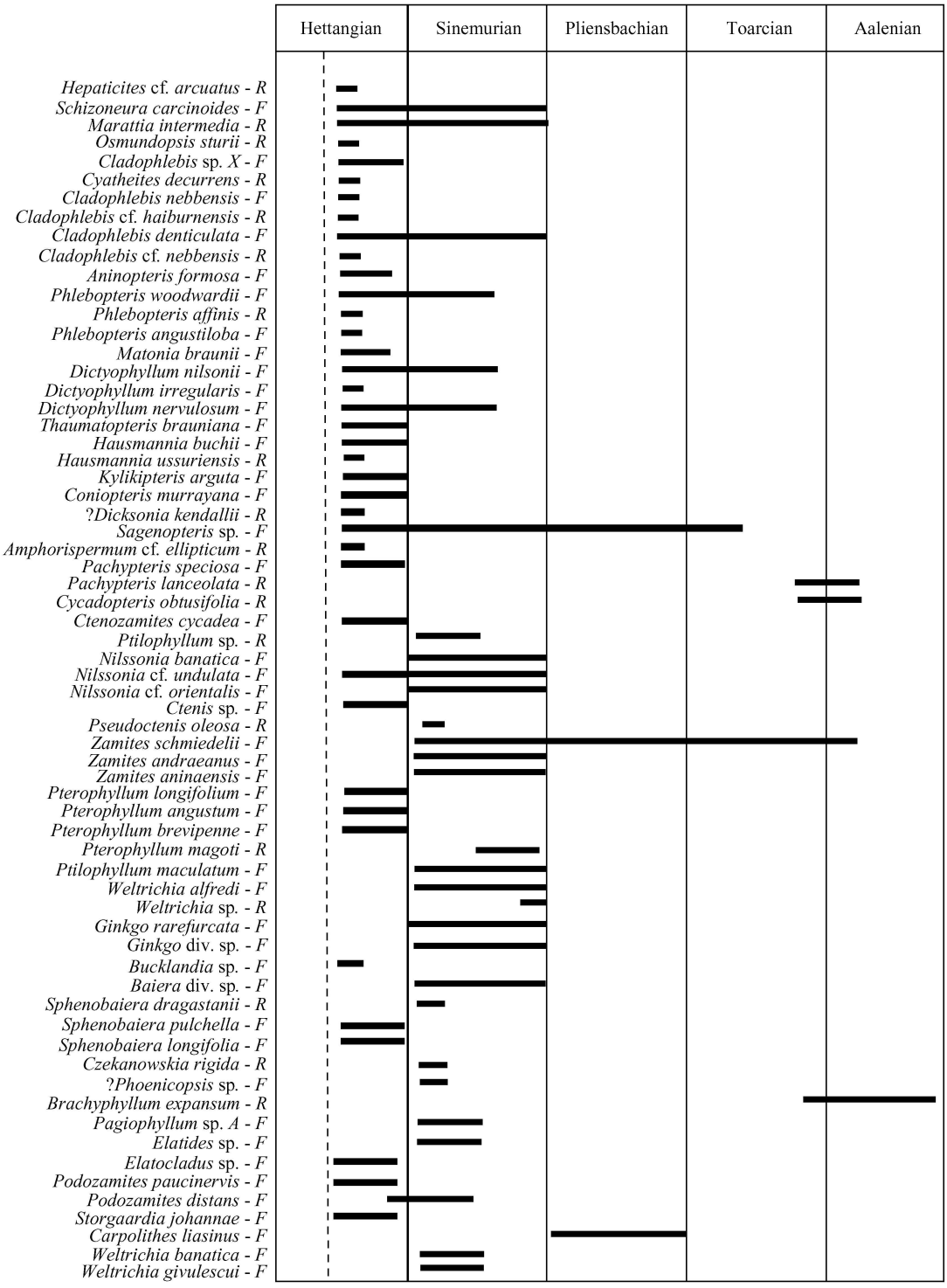

Fig. 3. Taxon ranges for the Resita Basin, Getic Nappe. R, rare; F, frequent. Modified from Popa[4,5].

otanical material. Such a remarkable preservation is unique in Europe, and consequently, the Ponor Quarry recognition as a paleobotanical SSSI (Site of Special Scientific Interest).

As previously outlined, the gymnosperms are the most diverse component in these fossil assemblages. Seed ferns are represented by Caytoniales (*Sagenopteris nilssoniana*, *S. phillipsii*, *Amphorispermum* cf. *ellipticum*), Corystospermales (*Umkomasia* sp.) and Incertae sedis (*Pachypteris speciosa*, *P. rhomboidalis*, *Komlopteris nordenskioeldii*, *Ctenozamites cycadea*). The coal forming taxon *Pachypteris speciosa* commonly co-occurs with *Umkomasia* sp. in the Hettangian Valea Tereziei Member. These were probably swamp margin plants that co-existed with a range of conifers[34].

Cycads are diverse, with numerous species of *Nilssonia* (*N.* cf. *undulata*, *N.* cf. *orientalis*), and *Ctenis* (*C.* sp.). *Nilssonia* cf. *orientalis* is particularly important as it marks the *N.* cf. *orientalis* acme zone, typical of the Sinemurian of the Resita Basin[3,4,35]. Bennettites are even more numerous, represented by foliage, bark, branches, and reproductive structures. Foliage of the following taxa were recorded: *Zamites* (*Z. schmiedelii*, *Z. andraeanus*, *Z. aninaensis*), *Otozamites* (*O. mandelslohi*), *Pseudoctenis* (*P. oleosa*), *Pterophyllum* (*P. longifolium*, *P. angustum*, *P. brevipenne*, etc.), and *Ptilophyllum* (*P. maculatum*). Stem imprints (*Bucklandia* sp.), female reproductive structures (*Williamsonia latecostata*, with strong affinities to *Williamsonia haydenii*), and male reproductive structures (*Weltrichia givulescui*, *W. alfredii*, *Weltrichia banatica*) are also common. The organ associations are the following: *Zamites aninaensis-Weltrichia givulescui*, *Zamites schmiedelii-Weltrichia banatica*, *Ptilophyllum maculatum-Weltrichia alfredii*[36]. *Zamites* and *Ptilophyllum* species are important coal forming plants. They occur most often in the roof shale of the coal seams, together with fern foliage such as *Cladophlebis denticulata* and *Ginkgo* div. sp. and probably grew during the final phase of peat swamp development.

Ginkgoales are represented by *Ginkgo* (*G. rarefurcata*, *G. parasingularis*, etc.) *Sphenobaiera* (*S. pulchella*, *S. longifolia*), whereas Czekanowskiales are represented by *Czekanowskia* (*C. rigida*) and *Phoenicopsis* (*P. potoniei*). *Phoenicopsis* is a useful cold climate indicator. It signifies Siberian influences in the Resita and Holbav basins, and it is probably an upland floras representative.

Conifers are represented by Cheirolepidiaceae (*Ourostrobus* sp., *Brachyphyllum* sp.) and incertae sedis (*Podozamites paucinervis*, *Storgaardia johannae*, *Geinitzia* sp., *Pagiophyllum* sp., *Elatocladus* sp.). They were important elements in the Hettangian marshlands in the Resita Basin.

The marls of the Middle Jurassic Tilva Zinei Formation yield a transported flora with *Pachypteris lanceolata*[4], *Nilssonia* sp., and *Brachyphyllum expansum*[37]. Semaka[38] cited Aalenian *Nellostrobus* div. sp., but the identification is doubtful.

Popa[4,39] described the first Mesozoic tetrapod tracks in Romania (*Batrachopus* cf. *deweyi*), from Ponor Quarry, in Anina, which increased the importance of this quarry as a future SSSI. The Ponor Quarry, with its unique exposures, high plant diversity and preservation, represents one of the most important paleobotanical sites in Europe.

Correlation between paleobotanical, palynological and sedimentological data is currently undertaken. Antonescu[40] analysed a sample of refractory clay close to the Hettangian-Sinemurian boundary, stating that the sporomorph content indicates generally the Lower Jurassic.

A Hettangian-Sinemurian floral change was recorded in the Resita Basin[4,5] and it was explained by a climatic shift, from colder, drier conditions during the Hettangian, to warmer, wetter conditions during the Sinemurian. The Hettangian *Thaumatopteris brauniana* taxon range zone includes besides the Dipteridaceous marker, *Coniopteris murrayana*, *Kylikipteris arguta*, *Hausmannia buchii*, *H. ussuriensis*, *Amphorispermum ellipticum*, *Pachypteris speciosa*, *Ctenozamites cycadea*, *Pterophyllum longifolium*, *P. angustum*, *Sphenobaiera longifolia*, *S. pulchella*, *Storgaardia johannae*, etc. This diverse assemblage with ferns, seed ferns and bennettites can be correlated throughout the Resita Basin[4,5]. The Sinemurian Acme zone containing *Nilssonia* cf. *orientalis*, *Cladophlebis denticulata*, *Osmundopsis sturii*, *Nilssonia banatica*, *Zamites schmiedelii*, *Zamites andraeanus*, *Zamites aninaensis*, *Weltrichia givulescui*, *W. banatica*, and

Ginkgo div. sp., is a consistent biostratigraphic unit thorough the whole Resita Basin.

Anina, with its exquisite and diverse flora, includes two paleobotanical SSSIs candidates (Ponor Quarry and Pit No. 1 colliery tip). The diversity of the flora, its high degree of preservation, the tetrapod footprints, and the associated continental ichnofacies makes Anina a valuable candidate for a fossil-Lagerstatte locality[41].

2 The Hateg Basin (Getic Nappe)

Laufer[42] published the first data regarding the Early Jurassic flora of the Hateg Basin, based on material collected from Cioclovina village, Arsului Hill more precisely (Fig. 2). Unfortunately, the type material is lost, so his lists are not verifiable. Semaka[14,15,43—47] cited the Pui locality, in the same basin, as being fossiliferous. Stilla[48] described in detail the sedimentary sequence of the Cioclovina Mesozoic deposits, including the Lower Jurassic continental sequence, discussing paleobotanical aspects, such as plant occurrence, and stratigraphy.

3 The Holbav Basin (Getic Nappe)

Holbav is a small basin close to Brasov, with both compressed and permineralized plant fossils, of Early Jurassic age (Fig. 2). This small basin hosted a range of mines, such as Victoria, Concordia, Holbav, Valea Lata and 1 May underground mines. The Holbav quarry was particularly rich in fossil plants. The formal stratigraphy of the basin was established by Dragastan and Popa[49], who defined the Holbav Formation, with two members: the Concordia Member (Lower Hettangian), and the Piriul Crucii Member (Middle Hettangian-Pliensbachian), overlain by a marine formation. The Holbav Formation includes conglomerates, sandstones, mudstones, and coal seams (brown coals). A volcaniclastic sequence within the Piriul Crucii Member includes tuffs and trachytes. In these tuffs, Vilceanu[50] recorded permineralized woods, while Raileanu et al.[51] detailed the structure of the coalfields.

Stur[19] described plant fossils collected from Holbav, followed by Semaka[43,52—54,55] who reviewed the entire flora of the basin. Givulescu[56,57] also contributed taxonomic and paleoecologic studies, while Dragastan and Popa[49] expanded paleoecological and sedimentological aspects. Mateescu[58] approached paleobotanical aspects in his coal petrography contribution regarding the Holbav Basin.

Totally, the Holbav flora includes about 80 taxa. The Holbav pteridophytes include Osmundaceous ferns (*Todites* cf. *williamsonii*), Matoniaceae (*Phlebopteris dunkerii*, *P.* cf. *muensterii*), Dipteridaceae (*Dictyophyllum* cf. *nathorstii*, *Clathropteris meniscioides*), and incertae sedis (*Cladophlebis denticulata*). Gymnosperms include Corystospermales (*Pachypteris rhomboidalis*), Cycadales (*Nilssonia* cf. *undulata*, *Paracycas* sp., *Ctenis grandifolia*), Bennettitales (*Ptilophyllum rigidum*, *Pterophyllum magoti*, *P. neagui*, *Taeniopteris* sp.), Czekanowskiales (*Phoenicopsis potoniei*), and conifers (*Geinitzia* sp.).

4 The Cristian Basin (Getic Nappe)

The Cristian Basin is a small Mesozoic basin in the easternmost part of the Getic Nappe, near Brasov city (central Romania, Figs. 2, 4), although the structural settings of the basin is still disputed[2]. The 50 m thick Sinemurian continental sequences are represented by sandstones, mudstones and coals, overlain by marine sediments. Significant colliery tips occur along the Caldarii and Fabricii valleys.

Very well preserved compression and permineralized floras were recorded, although drifted and fragmented. Popa[4,59] and Guignard et al.[60] investigated a seed fern collected from Cristian. Excepting seed ferns, the compression flora includes *Otozamites mandelslohi*, *O. molinianus*, and *Desmiophyllum* sp. The permineralized woods are currently under study.

5 The Sirinia Basin (Danubian units)

The Sirinia Basin is the westernmost Danubian units sedimentary basin (Fig. 2). It contains both continental and marine Lower Jurassic sediments, described as the Cozla facies (continental), and Munteana facies (marine). Drifted plant fragments in the marine deposits are evidence of paralic influence. Structurally, the Sirinia Basin has a western segment, the Cozla-Camenita Syncline, and an eastern, main zone, the Sirinia Basin sensu-stricto. Numerous Early Jurassic plant localities occur in the Sirinia Basin, such as Bigar, Cozla, Pregheda, Chiacovat, Stanca, Pietrele Albe, etc. (Table 1, Fig. 4), all of them former coal mines.

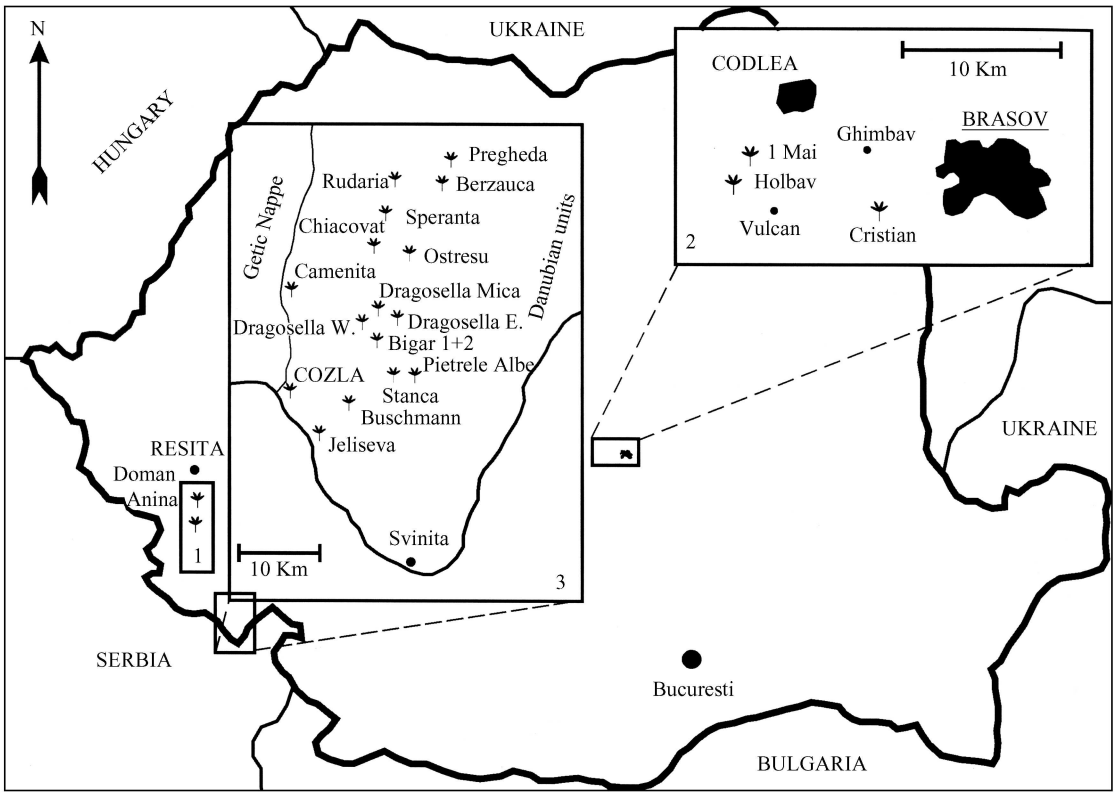

Fig. 4. Occurrence of localities yielding Early Jurassic plants in Romania.

The coal measures of the Sirinia Basin (the Cozla Facies) are Hettangian-Sinemurian in age. The sucessions begin with a thick conglomeratic, quartzitic, basal sequence (the so called "Cioaca Borii" conglomerates), overlain by sandstones, mudstones and coal seams. Significant lateral facies changes are common in the basin.

Raileanu[61] cited two plant taxa from Cozla, Semaka[62] published geological data with regard to the Cozla area, while the paper of Semaka[63] was the first review of the Early Jurassic flora of the Sirinia Basin. A series of papers dealing with the Sirinia Basin paleobotany was published later[44,64,65]. The work of Semaka[65] was the first comprehensive monograph of the Jurassic plants of the Sirinia Basin. Mateescu[66] included paleobotanical studies related to coal petrography, and Preda et al.[67] listed new taxa from the area.

The impression flora is less well preserved than that of the Resita Basin, but it is at least as diverse as the latter, based on preliminary estimates of about 110 species. Sphenopsids (*Equisetites* div. sp., *Schizoneura carcinoides*), are common. Ferns belong to Matoniaceae (*Phlebopteris* div. sp.), incertae sedis (*Cladophlebis* div. sp.), Dipteridaceae (*Thaumatopteris brauniana*, *Dictyophyllum* div. sp.). Cycads (*Nilssonia* sp., cf. *Beania* sp.) and bennettites (*Zamites*, *Otozamites*, *Pterophyllum*) are also common, while conifers such as *Pagiophyllum*, *Geinitzia*, and *Brachyphyllum* are abundant. The Sirinia flora is currently under revision.

6 The Presacina Basin (Danubian units)

The Presacina Basin is an intermediary basin between the Sirinia and Cerna-Jiu Basins (Fig. 2). It contains Mehadia (along the Valea Mare Valley), a locality with a less diverse, and less well preserved compression flora, Hettangian-Sinemurian in age. The formal stratigraphy has not been formally defined.

Iliescu and Semaka[68] published the first paleobotanical study of Mehadia, indicating the common occurrence of the Matoniaceous fern *Phlebopteris angustiloba*. Semaka[69] reviewed the Mehadia flora, citing *Marattia hoerensis*, *Nilssonia polymorpha*, together with other several taxa, also under revision.

7 The Cerna-Jiu Basin (Danubian units)

The easternmost basin of the Danubian structural

units is the Cerna-Jiu Basin, including several important, highly diverse localities, such as Schela, Obirsia-Closani, Baia de Arama, of which Schela (Figs. 1, 4) is the richest in plant fossils. This basin incorporates localities from the Mehedinti Plateau, which are sometimes assigned to a separated Mesozoic Basin, the Cosustea Basin.

The coal measures of the Cerna-Jiu Basin are Hettangian-Sinemurian in age, metamorphosed in some areas (in Closani, graphite was extracted), with a rich, although not well preserved flora.

Manolescu[70], and Draghici and Semaka[71] listed plant taxa from Baia de Arama area, and Semaka[72], and Semaka et al.[73] discussed in detail the phytostratigraphy of Schela. Draghici et al.[74] listed plants from Cerna Virf, while Zberea et al.[75] listed plants from Crasna. Preda[76], Preda et al.[77,78], and Badaluta et al.[79] dealt with plants from the Mehedinti Plateau, Schela, and from Obirsia Closani.

8 The Suncuius Basin (Bihor Autochthonous)

The Suncuius Basin is the northernmost basin in Romania (Fig. 2) with Lower Jurassic continental deposits. The compression flora of the Suncuius Basin is not highly preserved, with more than 40 taxa which require taxonomic revision.

Semaka[80] was the first to research the Suncuius flora, pointing to *Selenocarpus muensterianus* as a dominant taxon. Givulescu and Czier[81] and Czier[82—84] reviewed the flora. Popa et al.[85] discussed the dipteridaceous fern *Thaumatopteris brauniana* from Suncuius, and outlined the lithostratigraphy and biostratigraphy of the Lower Jurassic deposits of this basin.

The Suncuius Formation includes three members: Banlaca, Recea (Lower Hettangian-Lower Sinemurian, plant bearing sequence), and Valea Boiului Members[85,86].

The flora includes sphenophytes (*Equisetites* div. sp.), ferns, such as Dipteridaceae (*Thaumatopteris brauniana*), Matoniaceae (*Selenocarpus muensterianus*), and incertae sedis (*Cladophlebis* div. sp.). Gymnosperms are also diverse, including bennettites and cycads.

9 Central Dobrogea

A Late Bathonian-Early Callovian compression flora from Tichilesti Valley, in eastern Romania (central Dobrogea), was described by Dragastan and Barbulescu[87], with *Williamsonia danubii* (associated with *Ptilophyllum pecten*), *Brachyphyllum aureliae* and *Androstrobus zamioides*. The degree of preservation of this flora is poor.

10 Conclusions

The Jurassic continental sequences of Romania are confined to the South Carpathians and to the Apuseni Mountains, where they are typically Early Jurassic (Hettangian-Sinemurian) in age, belonging to the Eurosinian Province. Compression floras are most common, but permineralized floras are locally represented, in Holbav and Cristian Basins. The richest and the best preserved Early Jurassic flora occurs in the central area of the Resita Basin, in Anina, a possible fossile-Lagerstatte locality, where the phytostratigraphy has the highest resolution and a floral change at the Hettangian-Sinemurian boundary was recorded. The Romanian Early Jurassic floras occurred on the northern margin of the Tethys Ocean, at 20°—30°N, with the exception of the Suncuius flora, which had a higher, unknown yet latitudinal position. The Romanian floras need a thorough systematic, taxonomic and phytostratigraphic revision, especially those confined to the basins of the Danubian units.

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