Geobios 51 (2018) 559–570

Available online at ScienceDirect www.sciencedirect.com

Elsevier Masson France EM|consulte www.em-consulte.com

GEOBIOS

Original article

First palynological data from the Jurassic South Xiangshan Formation (Nanjing area, China)☆

Artai A. Santos [a,*], Xin Wang [b], Qiang Fu [b], José B. Diez [a]

[a] Departamento de Xeociencias Mariñas e Ordenación do Territorio, Universidade de Vigo. 36200, Vigo, Spain
[b] Chinese Academy of Sciences, Nanjing 210008, People's Republic of China

ARTICLE INFO

Article history:
Received 26 October 2017
Accepted 2 October 2018
Available online 9 October 2018

Presented by Borja Cascales-Miñana

Keywords:
Xiangshan Flora
Xiangshan Group
South Xiangshan Formation
Toarcian
Early Jurassic
Palynostratigraphy
Asia

ABSTRACT

The outcrops of the Xiangshan Group have been studied since the beginning of the twentieth century, yielding a rich macroflora (the Xiangshan Flora), mainly from the lower part of the Xiangshan Group (South Xiangshan Formation). Nevertheless, no palynological data have been published so far from the South Xiangshan Formation. The present study provides the first palynostratigraphic data of the South Xiangshan Formation. More than 50 fossil taxa from 30 fossil genera have been identified, allowing for a more accurate dating. The most characteristic taxa are *Polycingulatisporites triangularis*, *Quadraeculina anellaeformis*, *Manumia delcourtii*, *Ischyosporites variegatus*, *Callialasporites turbatus*, *C. trilobatus*, *C. minus*, and *Sestrosporites pseudoalveolatus*, suggesting a late Toarcian-late Aalenian age for the South Xiangshan Formation. These results are consistent with previous studies suggesting a middle-late Early Jurassic age for this formation; consequently, the most probable age for the South Xiangshan Formation is late Toarcian (late Early Jurassic).

1. Introduction

In this study, we present the first palynological assemblage found in the upper levels of the lower part of the Xiangshan Group (Nanjing area, China). The lower part of the Xiangshan Group has been named in different ways depending on the region, namely the South Xiangshan Fm. (= Nanxiangshan Fm.) or Moshan Fm. (Ju, 1987; Wang et al., 2005). The palynoflora studied herein comes from the Nanjing area, and the name used below will be South Xiangshan Fm. (Table 1). So far, only one palynological study has been published for the upper part of the Xiangshan Group (North Xiangshan Fm.; Huang, 2000), which attributes this formation to the Middle Jurassic.

The strata of the South Xiangshan Fm. came into the attention of geologists in the 19th century (Richthofen, 1912) and has aroused the interest of palaeobotanists since the early 20th century. The first references were published by Liu and Zhao (1924) and Sze (1931), who described a macroflora comparable to well-known European floras such as those documented by Harris (1961). Later on, palaeobotanical findings enriched the knowledge of the Xiangshan Flora (Cao, 1982, 1998, 2000; Wang et al., 1982, 2005; Huang, 1983, 1988; Yao, 2000). Huang (1983) described new specimens of the Xiangshan Flora from the South Xiangshan Fm., including 63 species from 38 genera, and among which are 4 new fossil species and 1 new fossil genus. The flora is related to the *Dictyophyllum-Clathropteris* assemblage of Sze (1956). The dominant taxa are the Cycadophytes, although the ferns, Equisetales and Ginkgoaceae are diverse. However, conifers and Lycopodiales are scarce. Huang (2000) shows that the palynological assemblage of the North Xiangshan Fm. is dominated by gymnosperm pollen, mainly *Classopollis* spp. In this assemblage she identified 77 fossil species from 37 fossil genera. According to the proportion of preserved taxa, this author attributed the North Xiangshan Fm. to the Middle Jurassic. According to Huang (2000), the vegetation consisted of lush forests of Cheirolepidaceae along with some Cycadaceae, Ginkgoaceae and Coniferae trees, as well as some pteridophytes. Other stratigraphic correlations attribute the North Xiangshan Fm. to the Middle Jurassic based on lithostratigraphy (Ju, 1987) and biostratigraphy of charophytes (*Eucalistachara*), gastropods (*Amnicola*), ostracods, conchostracans (*Psilunio sinensis, Lamprotula cremeri, Cuneopsis sichuanensis*, and *Undulatula* sp.), which are indicators of the Middle Jurassic in the region (Wan, 1987).

While the South Xiangshan Fm. has been traditionally considered as Lower Jurassic based on lithostratigraphic correlations (Ju,

☆ Corresponding editor: Borja Cascales-Miñana.

* Corresponding author.
E-mail address: artaisl29@gmail.com (A.A. Santos).

https://doi.org/10.1016/j.geobios.2018.10.002
0016-6995/© 2018 Published by Elsevier Masson SAS.

Table 1
Correlation of the Xiangshan Group in the Jiangsu Province and in the Anhui Province (modified from Wang et al., 2005).

Group	Age	Formation		Lithology	Fossils
		Jiangsu Province (Nanjing area)	Anhui Province		
Xiangshan Group (fluvio-lacustrine deposits)	Middle Jurassic (Ju, 1987; Wan, 1987; Huang, 2000)	North Xiangshan Fm. (Beixiangshan Fm.)	Luoling Fm.	Upper part: variegated sandstones and shales (Ju, 1987)	Microflora (Huang, 2000), ostracoda, conchostracoda, gastropods, and charophytes (Wan, 1987)
	Early Jurassic (Cao, 2000; Wang et al., 2005)	South Xiangshan Fm. (Nanxiangshan Fm.)	Moshan Fm.	Lower part: coal bearing strata (Ju, 1987)	Microflora (this article) and macroflora (Liu and Zhao, 1924; Sze, 1931; Cao, 1982, 1998, 2000; Wang et al., 1982, 2005; Huang, 1983, 1988; Yao, 2000)

1987) and on the presence of macroflora such as *Scoresbya dentata*, Cao (1982) affirmed that the lower part of the Xiangshan Group (= South Xiangshan Fm.) cannot be younger than Early Jurassic, probably the late-middle Early Jurassic. Huang (1983) also argued that this macroflora is closely related to the Hsiangchi Flora and can be compared to the *Thaumatopteris* Zone of Eastern Greenland, concluding that the Xiangshan Flora must belong to the Early Jurassic. Others studies such as Cao (2000) and Wang et al. (2005) also considered that the plant-yielding South Xiangshan Fm. (lower part of the Xiangshan Group) is Early Jurassic.

In summary, the North Xiangshan Fm. (= upper part of the Xiangshan Group) is restricted to the Middle Jurassic, and the South Xiangshan Fm. (= lower part of the Xiangshan Group) is equivalent to the Early Jurassic, probably the late-middle Early

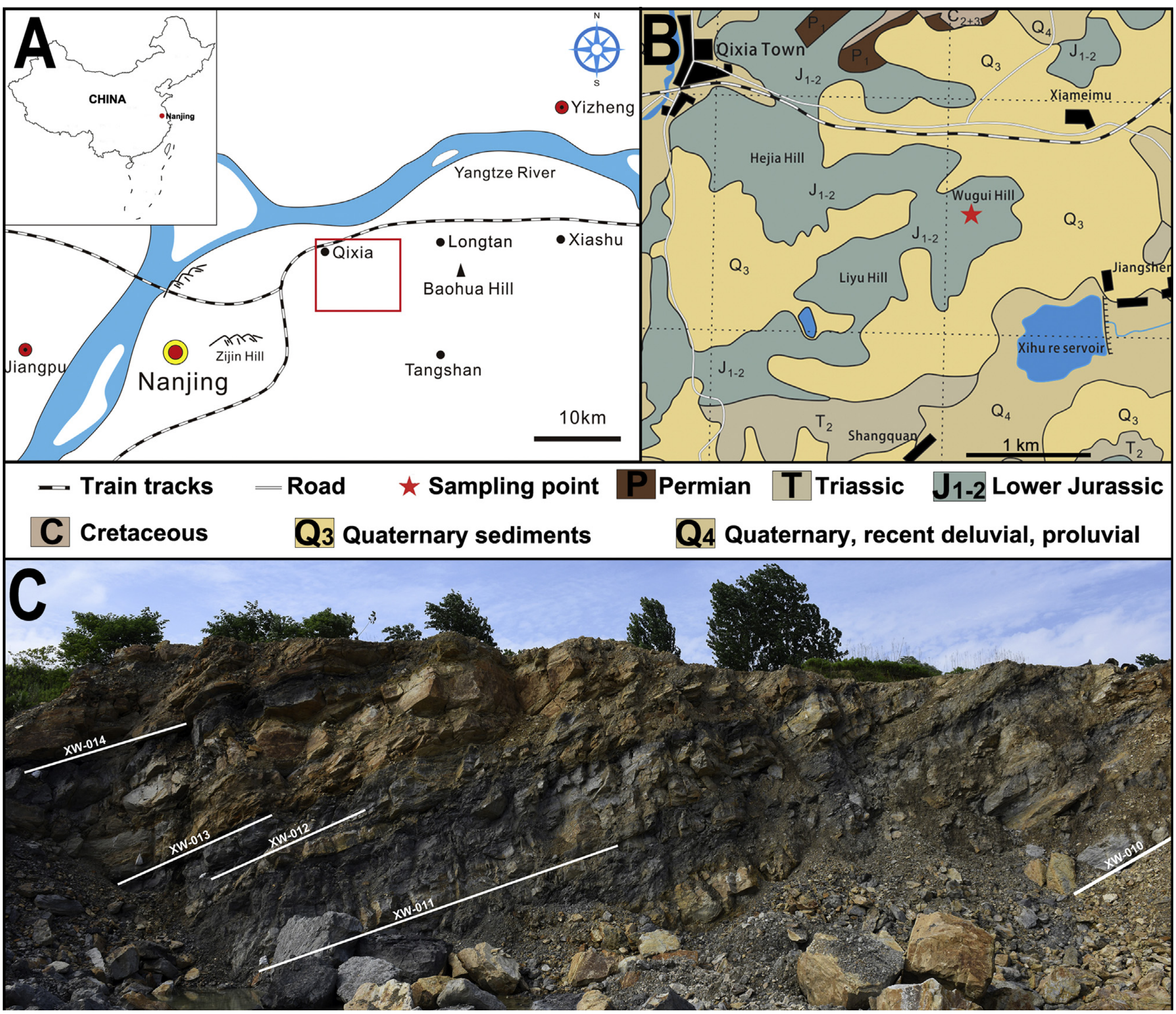

Fig. 1. A. Outline map of the outcrop locality in Nanjing, China. **B**. Geological setting of the Nanjing Area. **C**. Outcrop view of the South Xiangshan Fm. with the position of the palynology samples.

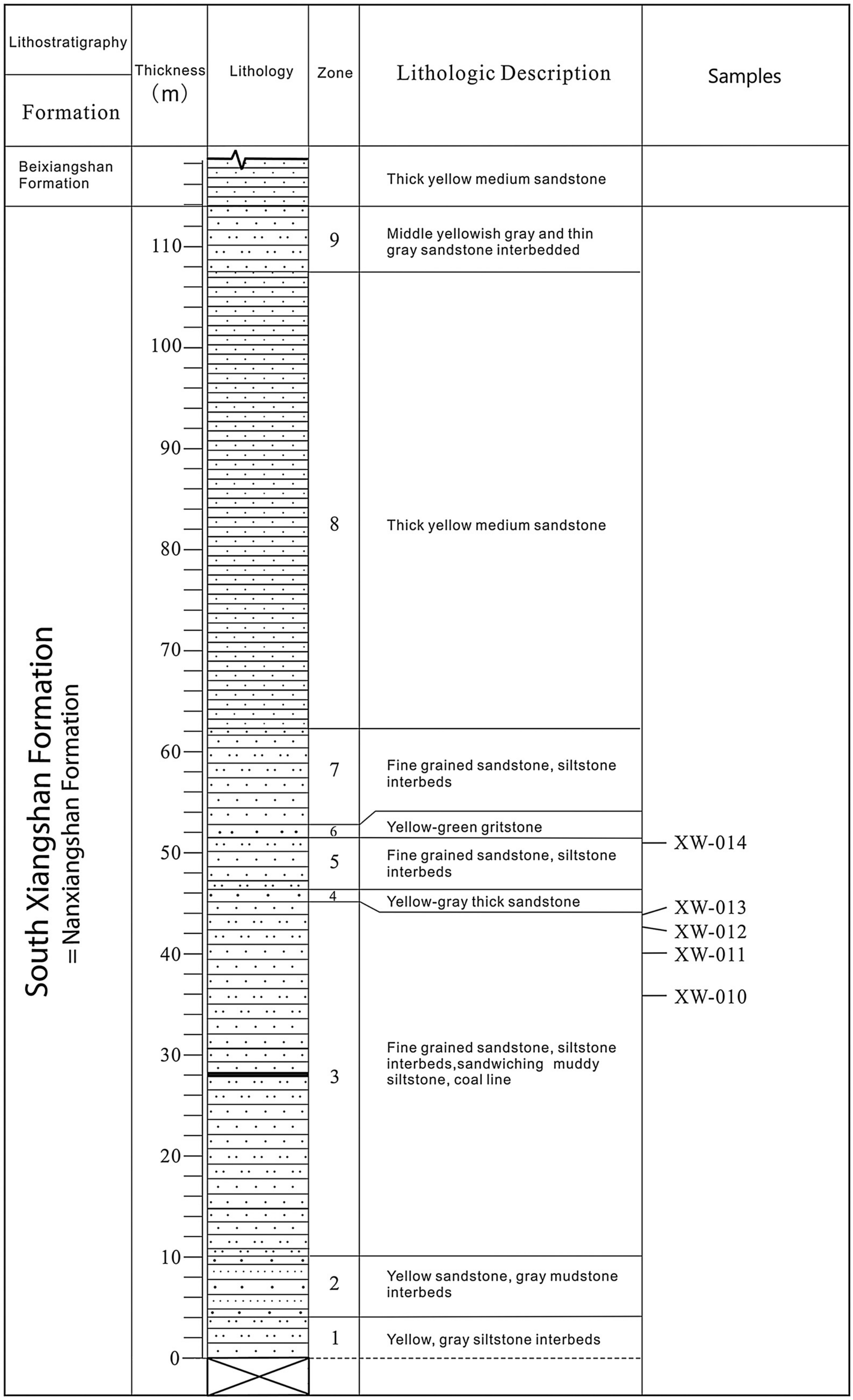

Fig. 2. Stratigraphic column of the South Xiangshan Fm. with the position of the palynology samples XW-10 to XW-14.

Table 2
Pollen and spores identified in the South Xiangshan Fm., with their botanical affinities.

Taxon	Botanical affinity
Spores	
Anapiculatisporites sp. (Fig. 4(N))	*Lycopodiaceae* (18)
Annulispora folliculosa (Rogalska, 1954) de Jersey, 1959 (Fig. 5(L))	Bryophyta, Sphagnales (15)
Contignisporites sp.	*Schizaeaceae* (7; 11; 21)
Cyathidites australis Couper, 1953 (Fig. 4(A))	*Dicksoniaceae, Cyatheaceae, DiPteridaceae, Matoniaceae* (13; 20; 21)
Cyathidites minor Couper, 1953 (Fig. 4(B))	*Dicksoniaceae, Cyatheaceae, DiPteridaceae, Matoniaceae* (13; 20; 21)
Deltoidospora minor Pocock, 1970 (Fig. 4(D))	*Cyatheaceae, Dicksoniaceae, DiPteridaceae, Matoniaceae* (1; 18; 20; 21; 27; 31)
Deltoidospora sp. (Fig. 4(C))	*Cyatheaceae, Dicksoniaceae, DiPteridaceae, Matoniaceae* (1; 18; 20; 21; 27; 31)
Dictyophyllidites harrisii Couper, 1958 (Fig. 4(G))	*Dipteridaceae, Matoniaceae* (1; 18; 20; 27)
Dictyophyllidites mortonii (de Jersey 1959) Playford et Dettmann, 1965 (Fig. 4(H))	*Dipteridaceae, Matoniaceae* (1; 18; 20; 27)
Gleicheniidites senonicus Ross, 1949 (Fig. 4(E))	*Gleicheniaceae* (1; 7; 18; 21; 4)
Gleicheniidites sp. (Fig. 4(F))	*Gleicheniaceae* (1; 7; 18; 21; 4)
Ischyosporites sp. (Fig. 5(G))	*Schizaeaceae* (7; 18; 10; 16; 21)
Ischyosporites variegatus (Couper, 1958) Schultz, 1967 (Fig. 4(L))	*Schizeaceae* (10; 16)
Leptolepidites verrucatus Couper, 1953 (Fig. 5(A))	*Lycopodiaceae* (7; 18)
Manumia delcourtii (Pocock, 1970) Dybkjær, 1991 (Fig. 4(K))	*Pteridaceae* (30)
Neoraistrickia ramosus (Balme et Hennelly, 1956) Hart, 1960 (Fig. 4(I))	*Lycopodiaceae* (1; 7; 18)
Osmundacidites wellmanii Couper, 1953 (Fig. 5(K))	*Osmundaceae* (*Osmunda*-type) (1; 7; 8; 18; 21)
Polycingulatisporites triangularis (Bolchovitina, 1953) Playford et Dettmann, 1965 (Fig. 5(J))	*Bryophyta, Sphagnales* (15)
Punctatosporites sp. (Fig. 4(M))	*Marattiaceae, Osmundaceae* (*Todites*-type) (8; 21; 23)
Retitriletes austroclavatidites (Cookson, 1953) Döring et al., 1963 (Fig. 5(C))	*Lycopodiaceae* (4; 18; 29; 32)
Retitriletes clavatoides (Couper, 1958) Doring et al., 1963 (Fig. 5(B))	*Lycopodiaceae* (4; 18; 29; 32)
Sestrosporites pseudoalveolatus (Couper, 1958) Dettmann, 1963 (Fig. 4(O))	*Lycopodiaceae* (4; 18; 24)
Striatella scanica (Nilsson, 1958) Filatoff et Price, 1988 (Fig. 5(D))	*Pteridaceae* (11)
Striatella seebergensis Mädler, 1964 (Fig. 5(E, F))	*Pteridaceae* (11)
Pollen grains	
Alisporites robustus Nilsson, 1958 (Fig. 6(O))	Pteridosperms (Corystospermales) (1; 6; 18; 19; 21; 26; 31)
Alisporites sp. (Fig. 6(M))	Pteridosperms (Corystospermales) (1; 6; 18; 19; 21; 26; 31)
Callialasporites dampieri (Balme, 1957) Dev, 1961 (Fig. 5(P))	*Araucariaceae* (6; 18; 21)
Callialasporites minus (Tralau, 1968) Guy, 1971 (Fig. 5(Q))	*Araucariaceae* (6; 7; 18)
Callialasporites trilobatus (Balme, 1957) Dev, 1961 (Fig. 5(O))	*Araucariaceae* (6; 7; 18)
Callialasporites turbatus (Balme, 1957) Schulz, 1967 (Fig. 5(R))	*Araucariaceae* (6; 7; 18)
Cerebropollenites macroverrucosus (Thiergart, 1949) Pocock, 1970 (Fig. 5(H))	*Taxodiaceae, Coniferales* (5; 13; 14)
Chasmatosporites apertus (Rogalska, 1954) Nilsson, 1958 (Fig. 6(D))	*Cycadales, Ginkgoales, Gnetales* (5; 18; 21; 22; 33)
Chasmatosporites hians Nilsson, 1958 (Fig. 6(C))	*Cycadales, Ginkgoales, Gnetales* (5; 18; 22; 29; 31)
Chasmatosporites sp. (Fig. 6(B))	*Cycadales, Ginkgoales, Gnetales* (5; 13; 14; 18; 22; 29; 31)
Classopollis chateaunovi Reyre, 1970	*Cheirolepidiaceae* (1; 9; 25)
Classopollis classoides (Pflug, 1953) Pocock et Jansonius, 1961 (Fig. 6(N))	*Cheirolepidiaceae* (1; 9; 25)
Classopollis meyeriana (Klaus, 1960) De Jersey, 1973	*Cheirolepidiaceae* (1; 9; 21; 25)
Classopollis simplex (Danzé-Corsin et Laveine, 1963) Reiser et Williams, 1969 (Fig. 5(M))	*Cheirolepidiaceae* (1; 9; 25)
Cycadopites follicularis Wilson et Webster, 1946 (Fig. 6(I))	*Bennettitales, Cycadales, Ginkgoales, Peltaspermales* (18; 31)
Cycadopites sp. (Fig. 6(H))	*Williamsoniaceae, Cycadaceae; Ginkgoaceae; Peltaspermaceae* (2; 18; 21; 29; 31)
Ephedripites sp. (Fig. 6(F))	*Gnetales* (17)
Monosulcites minimus Cookson, 1947 (Fig. 6(J))	*Bennettitales, Ginkgoales* (4; 6; 18)
Monosulcites sp.	*Cycads, Bennettitales, Ginkgoales* (1; 4; 6; 12; 18)
Perinopollenites elatoides Couper, 1958 (Fig. 5(I))	*Taxodiaceae* (1; 13; 18; 21; 29; 31)
Platysaccus sp.	*Palyssiaceae* (21)
Podocarpidites sp. (Fig. 6(N))	*Podocarpaceae* (18)
Quadraeculina anellaeformis Maljavkina, 1949 (Fig. 6(E))	*Podocarpaceae Coniferales* (1; 18; 21; 28)
Quadraeculina enigmata (Couper, 1958) Xu et Zhang, 1980 (Fig. 6(A))	*Podocarpaceae* (18)
Quadraeculina minor (Pocock, 1970) Xu et Zhang, 1980 (Fig. 6(L))	*Podocarpaceae* (18)
Spheripollenites psilatus Couper, 1958	*Taxodiaceae* (18)
Vitreisporites pallidus Nilsson, 1958 (Fig. 6(K))	Pteridosperms (Caytoniales) (1; 6; 18; 21; 26; 29; 31; 34)
Fungi	
Indeterminate fungal spore A	Fungi
Indeterminate fungal spore B	Fungi

References: 1. Couper (1958); 2. Townrow (1960); 3. Dettmann (1963); 4. Potonié (1967); 5. Tralau (1968); 6. Van Konijnenburg-Van Cittert (1971); 7. Filatoff (1975); 8. Van Konijnenburg-Van Cittert (1978); 9. Harris (1979); 10. Van Konijnenburg-Van Cittert (1981); 11. Filatoff and Price (1988); 12. Pedersen et al. (1989); 13. Van Konijnenburg-Van Cittert and Van der Burgh (1989); 14. Van Konijnenburg-Van Cittert (1989); 15. Koppelhus (1991); 16. Van Konijnenburg-Van Cittert (1991); 17. Van Konijnenburg-Van Cittert (1992); 18. Boulter and Windle (1993); 19. Osborn and Taylor (1993); 20. Van Konijnenburg-Van Cittert (1993); 21. Balme (1995); 22. Batten and Dutta (1997); 23. Wang et al. (2001); 24. Abbink et al. (2004); 25. Ziaja (2006); 26. Traverse (2007); 27. Guignard et al. (2009); 28. Bonis (2010); 29. Mander et al. (2010); 30. Legrand et al. (2011); 31. Mander (2011); 32. Srivastava (2011); 33. Bonis and Kürschner (2012); 34. Gedl and Ziaja (2012)

Jurassic. Although a palynological study has been carried out on the North Xiangshan Fm. (Huang, 2000), such a study was still necessary to understand its southern counterpart. The present study aims to provide a more accurate palynostratigraphic age for the South Xiangshan Fm.

2. Geographical and geological settings

The samples for palynological preparation were collected from an outcrop of the South Xiangshan Fm. (= lower Xiangshan Group) in the NE suburb of Nanjing, Jiangsu, China (N32°08'19",

KEY TAXA	Early Jurassic					Middle Jurassic								
	pre-Pliensbachian	Pliensbachian		Toarcian		Aalenian			Bajocian		Bathonian			post-Bathonian
		early	late	early	late	early	middle	late	early	late	early	middle	late	
Ischyosporites variegatus	5, 24		2, 8, 21, 30	1, 6, 8, 11, 13, 14, 16, 17, 21, 30	1, 4, 6, 7, 8, 9, 10, 11, 13, 14, 16, 17, 21, 28, 30	6, 7, 8, 9, 10, 14, 18, 21	6, 18	6, 18	3	3, 47	3, 15, 47	3, 15, 47	3, 15, 47	12, 19, 23, 42, 47
Manumia delcourtii		17	2, 8, 17, 21, 28, 30	2, 8, 13, 16, 17, 21, 30, 31	2, 8, 13, 16, 17, 18, 21, 28, 30, 31	8, 17, 18, 21, 28	8, 17, 18, 21, 28	8, 17, 18, 21, 28	21					
Callialasporites turbatus			11, 18, 34	18	2, 6, 8, 9, 18, 21, 28, 30, 33, 34, 38, 39, 44	6, 9, 16, 18, 21, 28, 34, 35, 38, 39, 40, 41	6, 16, 18, 21, 28, 34, 35, 38, 39, 40, 41	6, 16, 18, 21, 28, 34, 35, 38, 39, 40, 41	16, 21, 33, 39, 46	16, 21, 33, 46	16, 33, 36, 45	16, 33, 36, 45	16, 33, 36, 45	12, 19, 23, 32, 33, 37, 47
Callialasporites trilobatus					2, 4, 28, 30, 56	18, 28, 43	18, 28, 43	18, 28, 43	3, 43, 46	3, 46	3, 36, 44, 45	3, 36, 44, 45	3, 36, 44, 45	19, 20, 25, 28, 32, 37, 42, 44, 47
Callialasporites minus					2, 6, 9	2, 6, 9, 17, 18, 48	2, 6, 17, 18, 48	2, 6, 17, 18, 48	2, 16, 17, 21, 48	2, 16, 17, 21, 48	2, 16, 36, 45, 48	2, 16, 36, 45, 48	2, 16, 36, 45, 48	19, 47, 48
Polycingulatisporites triangularis	2, 5, 28, 29, 49, 51, 52, 53		50	18, 50	18, 28	18, 28	18	18						
Quadraeculina anellaeformis	2, 5, 22, 24, 28, 29, 34, 49, 52, 53	2, 28, 34	2, 4, 18, 28, 30, 33, 34	2, 4, 28, 30, 33	2, 4, 6, 7, 18, 28, 30, 38	2, 6, 7, 18, 28, 38	2, 6, 18, 38	2, 6, 18, 38	2, 28, 33	2, 28, 33	2, 36			
Sestrosporites pseudoalveolatus					1, 2, 6, 18	6, 8, 18	6, 8, 18	6, 18	16, 21, 33, 46	16, 21, 26, 33, 46	16, 21, 26, 33, 36	16, 21, 26, 33, 36	16, 26, 33, 36	23, 26, 27, 28, 33, 47, 49, 54, 55

Fig. 3. Chart showing the biostratigraphic range of selected species identified in the South Xiangshan Fm. Substages following Ogg et al. (2016) international subdivisions. References: **1**. Palliani (1997); **2**. Batten and Koppelhus (1996); **3**. Sajjadi et al. (2008); **4**. Chahidi et al. (2016); **5**. Bonis et al. (2009); **6**. Hoelstad (1985); **7**. Ashraf et al. (2010); **8**. Koppelhus (1992); **9**. Barrón et al. (2010); **10**. Correia et al. (2017); **11**. Barrón et al. (2013); **12**. Barrón and Azerêdo (2003); **13**. Baranyi et al. (2016); **14**. Riding (1984); **15**. Haddoumi et al. (2016); **16**. Nielsen et al. (2003); **17**. Koppelhus (1992); **18**. Koppelhus and Hansen (2003); **19**. Van Erve et al. (1988); **20**. Cranwell and Srivastava (2009); **21**. Seidenkrantz et al. (1993); **22**. Li and Wang (2016); **23**. Braman and Koppelhus (2005); **24**. Kürschner and Herngreen (2010); **25**. Brenner and Bickoff (1992); **26**. Couper (1958); **27**. Kemp (1970); **28**. Lindström and Erlström (2007); **29**. Koppelhus (1991); **30**. Schnyder et al. (2016); **31**. Tramoy et al. (2016); **32**. Vijaya (2000); **33**. Lund and Pedersen (1985); **34**. Davies (1985); **35**. Palliani and Riding (2000); **36**. Gedl and Ziaja (2012); **37**. Batten and Dutta (1997); **38**. Feist-Burkhardt et al. (2009); **39**. Turner et al. (2009); **40**. Slater and Wellman (2015); **41**. Slater and Wellman (2016); **42**. Ied and Lashin (2016); **43**. Martínez et al. (2010); **44**. Mahmoud and Moawad (2000); **45**. Philippe et al. (1998); **46**. Riding et al. (2010); **47**. Borges et al. (2011); **48**. Jiang et al. (2008); **49**. Ilyina (1986); **50**. Goryacheva (2011); **51**. Fisher and Bujak (1975); **52**. Li and Wang (2016); **53**. Lindström and Erlström (2006); **54**. Vajda et al. (2013); **55**. Burden and Langille (1991); **56**. Martínez et al. (1999).

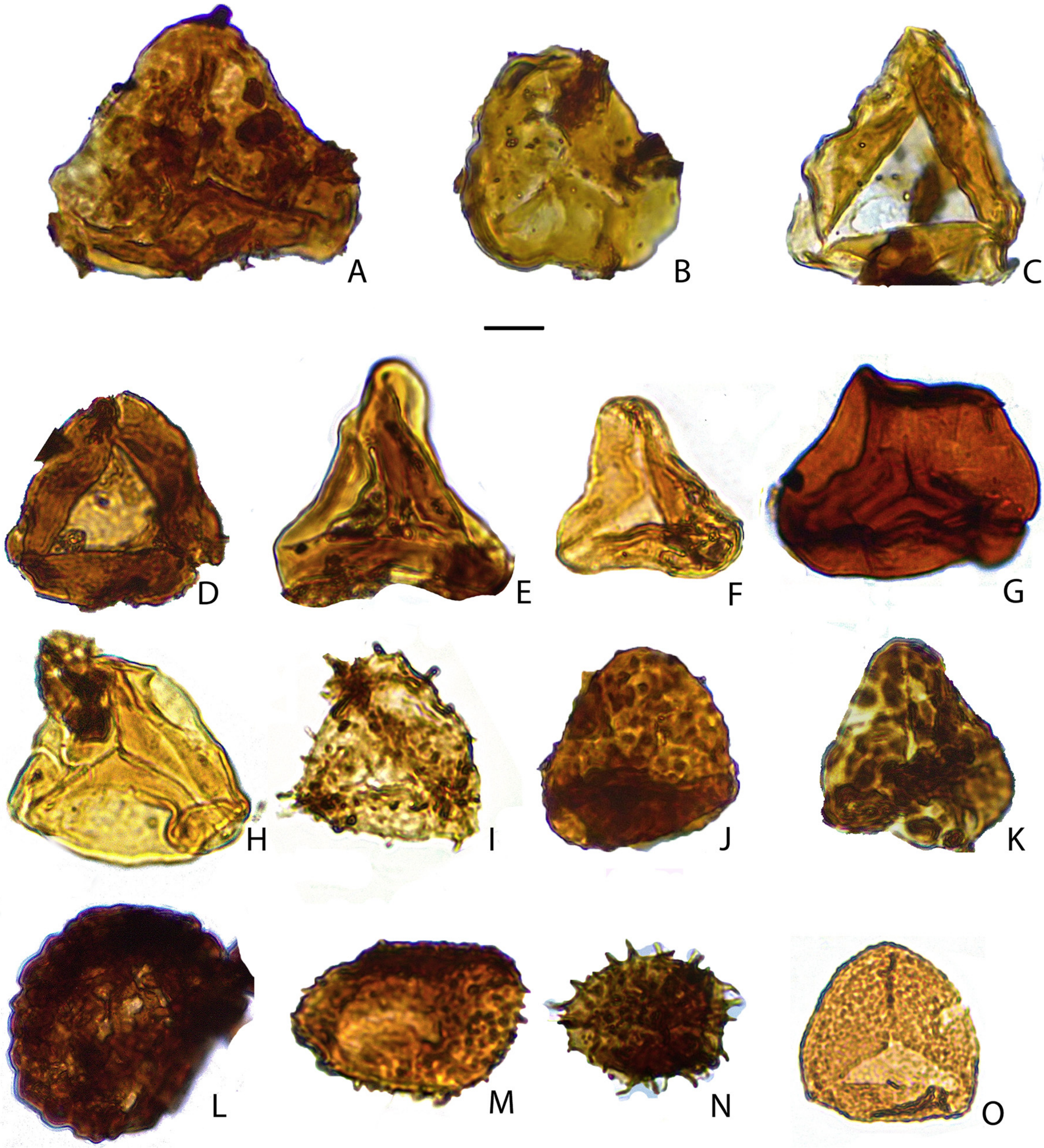

Fig. 4. A. *Cyathidites australis* Couper, 1953. **B**. *Cyathidites minor* Couper, 1953. **C**. *Deltoidospora sp*. **D**. *Deltoidospora minor* Pocock, 1970. **E**. *Gleicheniidites senonicus* Ross, 1949. **F**. *Gleicheniidites sp*. **G**. *Dictyophyllidites harrisii* Couper, 1958. **H**. *Dictyophyllidites mortonii* (de Jersey, 1959) Playford et Dettmann, 1965. **I**. *Neoraistrickia ramosus* (Balme et Hennelly, 1956) Hart, 1960. **J**. *Manumia* sp. cf. *M. delcourtii* (Pocock, 1970) Dybkjær, 1991. **K**. *Manumia delcourtii* (Pocock, 1970) Dybkjær, 1991. **L**. *Ischyosporites variegatus* (Couper, 1958) Schultz, 1967. *M. Punctatosporites* sp. *N. Anapiculatisporites* sp. **O**. *Sestrosporites pseudoalveolatus* (Couper, 1958) Dettmann, 1963. Scale bar: 10 μm.

E118°58’20”; Fig. 1(A, B)). The name “Xiangshan Group” derives from the Xiangshan Bed which was originally used in the Nanjing area (Li et al., 1935). The Xiangshan Group is distributed along the Yangtze River, in the Jiangsu area (where Nanjing outcrop is located) and it is divided into two units: the lower part of “Coal bearing strata” was called the South Xiangshan Fm.; it reaches almost 400 m in thickness. The upper part of the Xiangshan Group consists of “variegated sandstones and shales” named as the North Xiangshan Fm. (Ju, 1987). However, in the Anhui area, the upper part is named as the Louling Fm. and the lower part is named as the Moshan Fm. (Wang et al., 2005).

The plants of the Xiangshan Group constitute the Xiangshan Flora, mainly from the South Xiangshan Fm. In the An-Qing area of Anhui Province, the South Xiangshan Fm. is about 650 m thick, consisting of quartz sandstones with carbonaceous slate and siltstone intercalations. The upper part of the Moshan Fm. consists of quartz sandstones yielding numerous plants. The Xiangshan Group is characterized by a fluvio-lacustrine deposit environment (Wang et al., 2005; Wan, 1987).

3. Material and methods

Five samples were collected and studied for their palynological content from the South Xiangshan Fm (Fig. 1(C), 2). They have been processed with standard palynological techniques at the Department of Marine Geosciences and Territorial Planning at the University of Vigo, Spain. Sample processing involved crushing to a grain size between 1 and 2 mm followed by chemical treatment.

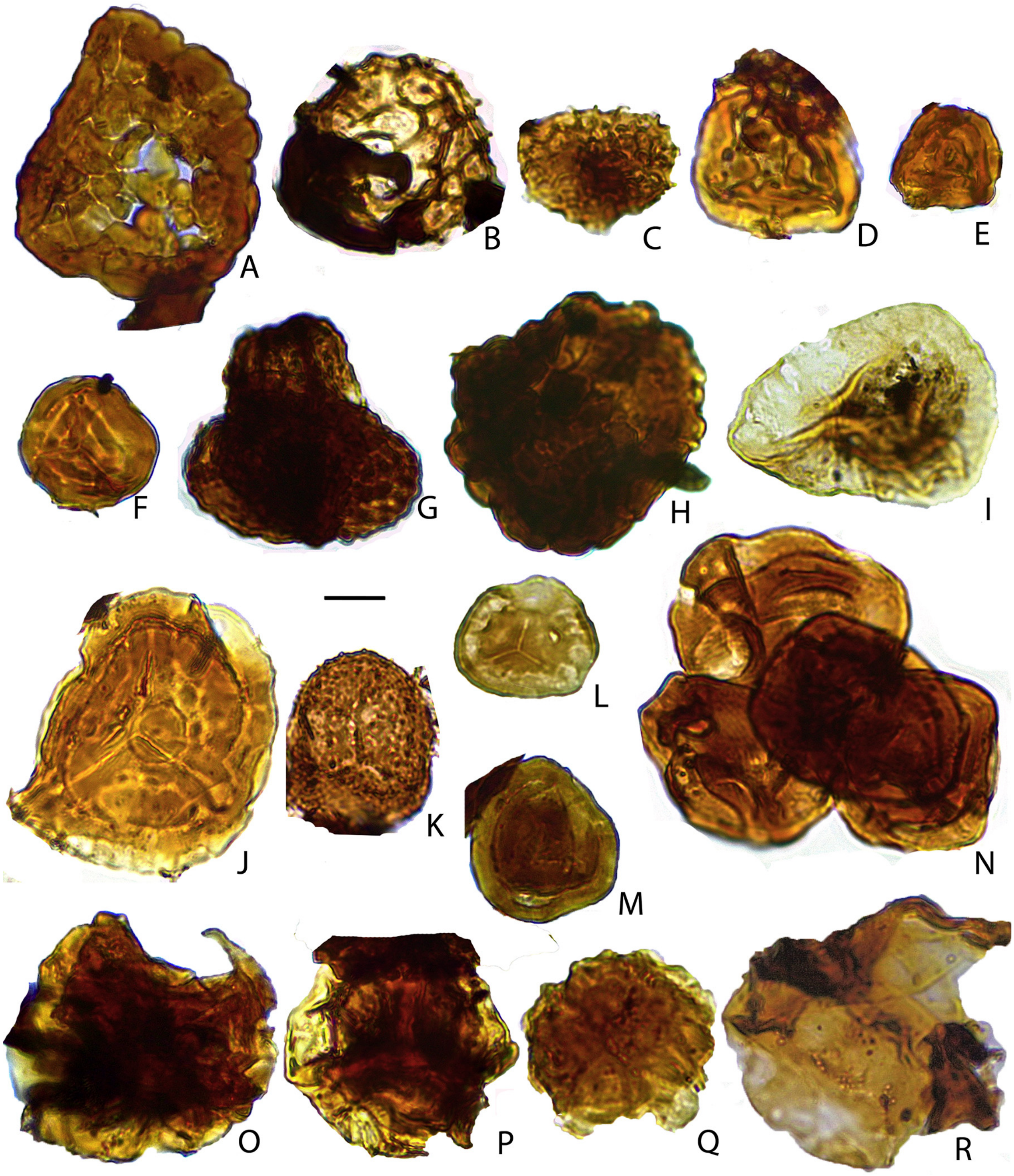

Fig. 5. A. *Leptolepidites verrucatus* Couper, 1953. **B**. *Retitriletes clavatoides* Döring, 1963. **C**. *Retitriletes austroclavatidites* (Cookson, 1953) Döring et al., 1963. **D**. *Striatella scanica* (Nilsson, 1958) Filatoff et Price, 1988. **E, F**. *Striatella seebergensis* Mädler, 1964. **G**. *Ischyosporites sp*. **H**. *Cerebropollenites macroverrucosus* (Thiergart, 1949) Pocock, 1970. **I**. *Perinopollenites elatoides* Couper, 1958. **J**. *Polycingulatisporites triangularis* (Bolchovitina, 1953) Playford et Dettmann, 1965. **K**. *Osmundacidites wellmanii* Couper, 1953. **L**. *Annulispora folliculosa* (Rogalska, 1954) de Jersey, 1959. **M**. *Classopollis simplex* (Danzé-Corsin et Laveine, 1963) Reiser et Williams, 1969. **N**. *Classopollis classoides* (Pflug, 1953) Pocock et Jansonius, 1961. **O**. *Callialasporites trilobatus* (Balme, 1957) Dev, 1961. **P**. *Callialasporites dampieri* (Balme, 1957) Dev, 1961. **Q**. *Callialasporites minus* (Tralau, 1968) Guy, 1971. R. *Callialasporites turbatus* (Balme 1957) Schulz, 1967. Scale bar: 10 μm.

Sample digestion by 10% HCl dissolved carbonates and 38% HF dissolved silicates. An additional treatment of 10% HCl was used to remove fluorurosilicates generated after HCl digestion. Finally, Schulze solution was added for 36 h and the residue was washed several times in distilled water and sieved through a 5 μm nylon mesh. For slide preparation, a droplet of each sample was mounted on a slide and finally, cover slips were fixed using Loctite 350. All five samples (XW-10 to XW-14) yielded palynomorphs. The palynological slides were analyzed in the Microscopy Labs at the University of Vigo with a Leica DM 2000 LED; the photos were taken with a Leica ICC50 W camera under × 1000 magnification.

4. Results

Samples are relatively rich in well-preserved palynomorphs. Due to the great similarity and stratigraphical proximity of the palynological samples, we have decided to consider the data as a single assemblage. The palynomorph taxa identified in the South Xiangshan Fm. are reported in Table 2.

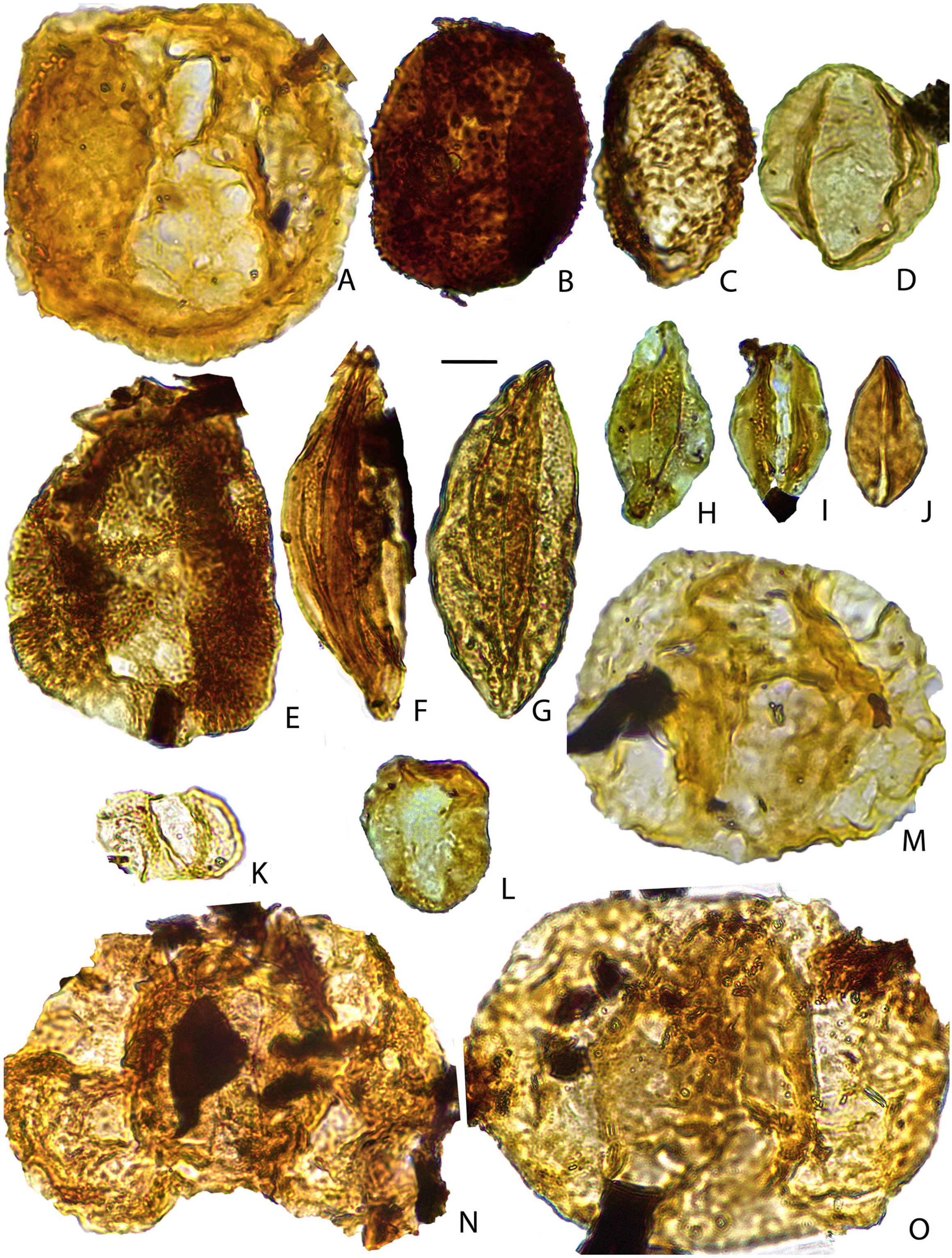

Fig. 6. A. *Quadraeculina enigmata* (Couper, 1958) Xu et Zhang, 1980. **B**. *Chasmatosporites* sp. **C**. *Chasmatosporites hians* Nilsson, 1958. **D**. *Chasmatosporites apertus* (Rogalska, 1954) Nilsson, 1958. **E**. *Quadraeculina anellaeformis* Maljavkina, 1949. **F**. *Ephedripites* sp. **G**. *Cycadopites* sp. **H**. *Cycadopites* sp. **I**. *Cycadopites follicularis* Wilson et Webster, 1946. **J**. *Monosulcites minimus* Cookson, 1947. **K**. *Vitreisporites pallidus* Nilsson, 1958. **L**. *Quadraeculina minor* (Pocock, 1970) Xu et Zhang, 1980. **M**. *Alisporites* sp. **N**. *Podocarpidites* sp. **O**. *Alisporites robustus* Nilsson, 1958. Scale bar: 10 μm.

5. Discussions

5.1. Palynostratigraphy

Several fossil taxa studied in the palynological assemblage from the South Xiangshan Fm. present a chronological distribution that covers almost all the Jurassic – e.g., *Striatella scanica*, *Callialasporites dampieri*, *Cyathidites* spp., *Alisporites robustus*, *Osmundacidites wellmanii*, *Gleicheniidites* spp., *Cycadopites* spp., *Dictyophyllidites harrisii*, *D. mortonii*, *Monosulcites* spp., *Chasmatosporites* spp., *Vitreisporites pallidus*, *Platysaccus* sp., *Podocarpidites* sp. and *Spheripollenites psilatus*, among others. However, some taxa have a more specific time range, as illustrated in Fig. 3 (only studies that show a clear identification and figuration of the taxa have been considered; taxa reported in Table 2 are figured in Figs. 4–6).

Striatella seebergensis is a common taxon during the Early Jurassic and early-Middle Jurassic, presenting its last appearance in the Middle Jurassic, for example in the Callovian of Greenland (Lund and Pedersen, 1985) and Iran (Hashemi-Yazdi et al., 2015). The first appearance of *Perinopollenites elatoides* is registered from the Rhaetian of Sweden (Vajda et al., 2013) and Poland (Orlowska-Zwolinska, 1983). *Retitriletes clavatoides* has its First Appearance Datum (FAD) at the beginning of the Early Jurassic, in the Triassic-Jurassic transition of Lyon (Courtinat et al., 1998); it has also been found in the Hettangian-Sinemurian of Denmark (Koppelhus, 1991), the Hettangian of Sweden (Larsson, 2009), and the Sinemurian of Morocco (Courtinat and Algouti, 1985). This taxon extends from the Early and Middle Jurassic up to its Last Appearance Datum (LAD) in the Early Cretaceous of England (Hesselbo et al., 1990). *Ischyosporites variegatus* has its FAD in the Late Triassic of Austria, in the Eiberg Basin (Bonis et al., 2009), and its LAD is in the Late Cretaceous (Braman and Koppelhus, 2005). *Manumia delcourtii* presents a narrower temporal range, with its FAD in the early Pliensbachian of Denmark (Koppelhus and Nielsen, 1994) and its LAD in the early Bajocian of Denmark (Seidenkrantz et al., 1993).

Some palynomorphs of the genus *Callialasporites* allow us to restrict the maximum age of the deposits, e.g., the presence of *Callialasporites turbatus*, which has its FAD in the late Pliensbachian of Portugal (Davies, 1985; Barrón et al., 2013) and Greenland (Koppelhus and Hansen, 2003). The FAD of *Callialasporites trilobatus* occurs in the late Toarcian of Argentina (Martinez et al., 1999), the Danish Basin (Lindström and Erlström, 2007), Kazakhstan (Schnyder et al., 2016), and Morocco (Chahidi et al., 2016). Similarly, *Callialasporites minus* has its FAD in the late Toarcian of Denmark (Hoelstad, 1985), Scotland (Riding et al., 1991), and Spain (Barrón et al., 2010). *Polycingulatisporites (Neochomotriletes) triangularis* has its FAD in the Late Triassic of China (Li and Wang, 2016), becoming common during the Early Jurassic, and has its LAD in the late Aalenian of Eastern Greenland (Koppelhus and Hansen, 2003). *Sestrosporites pseudoalveolatus* has a well-established age range, with its FAD in the late Toarcian of Italy (Palliani, 1997) and its LAD in the Cretaceous of Sweden (Vajda, 2001), England (Kemp, 1970), and Canada (Burden and Langille, 1991). *Quadraeculina anellaeformis* has its LAD in the middle Bathonian of Northwest Europe (Morbey and Dunay, 1978) and Poland (*Retrocostatum* and *Morrisi* ammonite zones; Gedl and Ziaja, 2012), but this last work does not show any picture of this taxon.

The presence of *Striatella seebergensis*, *Retitriletes clavatoides* and *Perinopollenites elatoides* would restrict the age of the South Xiangshan Fm. to the Early-Middle Jurassic. However, the LAD of *Quadraeculina anellaeformis* and *Manumia delcourtii* in the early Bathonian and the LAD of *Polycingulatisporites triangularis* in the late Aalenian indicate that the studied palynoflora is not younger than the late Aalenian. The FAD of *Manumia delcourtii* in the early Pliensbachian, as well as the FAD of *Callialasporites turbatus* in the late Pliensbachian, and the FAD of *Callialasporites trilobatus*, *C. minus* and *Sestrosporites pseudoalveolatus* in the late Toarcian suggest that the age of the palynological assemblage is not older than the late Toarcian. Therefore, the most probable age for the present assemblage is late Toarcian-late Aalenian (Fig. 3).

This result concurs with the palynological study from the North Xiangshan Fm. (Huang, 2000), suggesting a warm-humid climate where the vegetation consisted of forests of *Cheirolepidiaceae* along with some Cycadaceae, Ginkgoaceae and Coniferae, as well as some pteridophytes. Huang (2000) obtained the following percentages of palynomorphs: Bisaccates 4.2%, *Cycadopites* 5.7%, *Monosulcites* 0.3%, *Chasmatosporites* 3.6%, Pteridophytes 12.3%, and Gymnosperms 87.7%. Huang (2000) stated that "*the present assemblage is probably Middle Jurassic in age*", consistent with previous works; she justified the age of the formation using abundances of some taxa such as *Chasmatosporites* sp. or *Classopollis* sp. The reliability of this dating methodology is subject to various taphonomical factors because the abundance and preservation of taxa may be biased by taphonomic conditions. Despite the difference in methodology, Huang's (2000) results are consistent with previous (lithologic, biostratigraphic) data that assigned the North Xiangshan Fm. to the Middle Jurassic (Ju, 1987; Wan, 1987).

Based on the Middle Jurassic age of the North Xiangshan Fm., an Early Jurassic age was suggested for the South Xiangshan Fm. based on lithostratigraphic data and assemblage of the Xiangshan Flora (Ju, 1987). Cao (1982) suggested that the South Xiangshan Fm. would belong to the middle-late Early Jurassic. Cao (2000) considered that all plant-containing strata of the South Xiangshan Fm. (= lower part of the Xiangshan Group) belong to the Lower Jurassic. Huang (1983) related the Xiangshan Flora to the Hsiangchi Flora and emphasized their great affinities with the *Thaumatopteris* Zone of Eastern Greenland (Harris, 1937), concluding that the Xiangshan Flora must belong to the Early Jurassic.

In summary, the palynostratigraphic data provided in this study suggest a late Toarcian-late Aalenian age for the South Xiangshan Fm. This age is compatible and consistent with the previous stratigraphic and palaeobotanical (micro- and macro-) data discussed above. We conclude that the most probable age for the upper levels of the South Xiangshan Fm. is late Toarcian (late Early Jurassic).

5.2. Palaeoenvironment

From a palaeoenvironmental perspective (Table 2), the diversity of spores of Bryophytes (*Annulispora folliculosa*, *Polycingulatisporites triangularis*), palynomorphs with affinities of *Lycopodiaceae* (*Retitriletes* spp., *Neoraistrickia ramosus*, *Leptolepidites verrucatus*, and *Sestrosporites pseudoalveolatus*) and spores of ferns belonging to families such as Osmundaceae (*Osmundacidites wellmanii*), *Schizaeaceae* (*Ischyosporites spp.*) and Di*Pteridaceae*/ Matoniaceae (*Dictyophyllidites* spp., *Puntactisporites* sp.) suggest warm or warm-temperate climatic conditions and high humidity levels (Van Konijnenburg-Van Cittert, 2002). In addition, the diversity of Ginkgoales, Cycadales and Bennettitales (*Chasmatosporites* spp., *Monosulcites* spp., *Cycadopites* spp.) as well as palynomorphs of *Cheirolepidiaceae* (*Classopollis* spp.) with resistance to drought could indicate the existence of a dry season (Francis, 1983; Vakhrameev, 1991). However, some anemophilous pollen such as *Classopollis* spp. probably not only have an local origin, but also from other places.

Overall, the palynological association suggests a subtropical climate (high temperature and humidity) with a dry season. This interpretation is consistent with Vakhrameev (1991), who assigned a subtropical climate to the Euro-Sinian region, and with other palaeoenvironmental interpretations of the area, which stated that a "warm and humid environment was present in this area, at least during the rainy season" and suggest that "the seasonal climate is evidenced by the deciduous ginkgoaleans, czekanowskialeans, and some conifers in this region" (Huang et al., 2016).

6. Conclusions

The present study provides a more precise dating for the top of the South Xiangshan Fm., allowing a better contextualization of the macroflora of the Xiangshan Flora. The presence of *Polycingula-*

tisporites triangularis, *Quadraeculina anellaeformis* and *Manumia delcourtii* in combination with *Ischyosporites variegatus*, *Manumia delcourtii*, *Callialasporites turbatus*, *C. trilobatus*, *C. minus*, and *Sestrosporites pseudoalveolatus* suggest a late Toarcian to late Aalenian age. If we consider the previous data that suggest a late Early Jurassic age for this formation, we conclude that the most probable age for the South Xiangshan Fm. is late Toarcian. The presence of palynomorphs with affinities of Bryophytes, *Lycopodiaceae*, Osmundaceae, *Schizaeaceae*, Dipteriaceae and Matoniaceae affinities suggest warm or warm-temperate climatic conditions and high humidity levels (subtropical climate).

Acknowledgements

This research was supported by National Natural Science Foundation of China (41688103, 91514302, 91114201, 41572046), the Strategic Priority Research Program (B) of Chinese Academy of Sciences (Grant No. XDPB05, XDB18000000) and by the Government of Galicia (Spain) (Project GRC 2015/020). This is a contribution to UNESCO IGCP632 (Continental Crises of the Jurassic: Major Extinction Events and Environmental Changes within Lacustrine Ecosystems).

References

Abbink, O.A., Van Konijnenburg-Van Cittert, J.H.A., Visscher, H., 2004. A sporomorph ecogroup model for the Northwest European Jurassic-Lower Cretaceous: concepts and framework. Netherlands Journal of Geosciences 8, 17–31.

Ashraf, A.R., Sun, Y., Sun, G., Uhl, D., Mosbrugger, V., Li, J., Herrmann, M., 2010. Triassic and Jurassic palaeoclimate development in the Junggar Basin, Xinjiang, Northwest China – a review and additional lithological data. Palaeobiodiversity Palaeoenvironments 90, 187–201.

Balme, B.E., 1995. Fossil *in situ* spores and pollen grains: an annotated catalogue. Review of Palaeobotany and Palynology 87, 81–323.

Baranyi, V., Pálfy, J., Görög, Á., Riding, J.B., Raucsik, B., 2016. Multiphase response of palynomorphs to the Toarcian Oceanic Anoxic Event (Early Jurassic) in the Réka Valley section, Hungary. Review of Palaeobotany and Palynology 235, 51–70.

Barrón, E., Azerêdo, A., 2003. Palynology of the jurassic (Callovian-Oxfordian) succession from Pedrógao (Lusitanian Basin, Portugal). Palaeobiogeographical aspects. Neues Jahrbuch für Geologie und Paläontologie 227, 259–286.

Barrón, E., Ureta, S., Goy, A., Lassaletta, L., 2010. Palynology of the Toarcian-Aalenian Global Boundary Stratotype Section and Point (GSSP) at Fuentelsaz (Lower-Middle Jurassic, Iberian Range, Spain). Review of Palaeobotany and Palynology 162, 11–28.

Barrón, E., Comas-Rengifo, M.J., Duarte, L.V., 2013. Palynomorph succession of the upper pliensbachian-lower toarcian of the peniche section (Portugal). Comunicações Geológicas 100, 55–61.

Batten, D.J., Dutta, R.J., 1997. Ultrastructure of exine of gymnospermous pollen grains from Jurassic and basal cretaceous deposits in northwest Europe and implications for botanical relationships. Review of Palaeobotany and Palynology 99, 25–54.

Batten, D.J., Koppelhus, E.B., 1996. Chapter 20D. Biostratigraphic significance of uppermost Triassic and Jurassic miospores in Northwest Europe. In: Jansonius, J., McGregor, D.C. (Eds.), Palynology: principles and applications, 2, American Association of Stratigraphic Palynologists Foundation, Salt Lake City, pp. 795–806.

Bonis, N.R., Kürschner, W.M., 2012. Vegetation history, diversity patterns, and climate change across the Triassic/Jurassic boundary. Paleobiology 38, 240–264.

Bonis, N.R., Kürschner, W.M., Krystyn, L., 2009. A detailed palynological study of the Triassic-Jurassic transition in key sections of the Eiberg Basin (Northern Calcareous Alps, Austria). Review of Palaeobotany and Palynology 156, 376–400.

Bonis, N.R., 2010. Palaeoenvironmental changes and vegetation history during the Triassic-Jurassic transition. Ph.D. thesis, LPP Contribution, Series 29. 216 p.

Borges, M.E., Riding, J.B., Fernandes, P., Pereira, Z., 2011. The Jurassic (Pliensbachian to Kimmeridgian) palynology of the Algarve Basin and the Carrapateira outlier, southern Portugal. Review of Palaeobotany and Palynology 163, 190–204.

Boulter, M., Windle, T., 1993. A reconstruction of some middle Jurassic vegetation in northern Europe. Special Papers in Palaeontology 49, 125–154.

Braman, D.R., Koppelhus, E.B., 2005. Campanian palynomorphs. Dinosaur Provincial Park: a spectacular ancient ecosystem revealed. Indiana University Press, Bloomington, pp. 101–130.

Brenner, G.J., Bickoff, I.S., 1992. Palynology and age of the Lower Cretaceous basal Kurnub Group from the coastal plain to the northern Negev of Israel. Palynology 16, 137–185.

Burden, E.T., Langille, A.B., 1991. Palynology of Cretaceous and Tertiary strata, northeast Baffin Island, Northwest Territories, Canada: implications for the history of rifting in Baffin Bay. Palynology 15, 91–114.

Cao, Z.Y., 1982. On the occurrence of *Scoresbya* from Jiangsu and *Weichselia* from Zhejiang. Acta Palaeontologica Sinica 21, 343–348 [In Chinese with English abstract].

Cao, Z.Y., 1998. A study on the cuticles of some bennettitaleans from the lower part of the Xiangshan Group in Jiangsu and Anhui Provinces. Acta Palaeontologica Sinica 37, 283–294 [In Chinese with English abstract].

Cao, Z.Y., 2000. Some specimens of gymnospermae from the lower part of the Xiangshan Group in Jiangsu and Anhui Provinces with study on their cuticles. Acta Palaeontologica Sinica 39, 334–342 [In Chinese with English abstract].

Chahidi, S., Hssaida, T., Benzaggagh, M., Oumalch, F., Jaydawi, S., 2016. Palynostratigraphy and palaeoenvironment of the South Rifian Ridges (Morocco) Upper Domerian-Lower Toarcian sequence: a transitional domain between the Proto-Atlantic and the Tethys. Boletín Geológico y Minero 127, 375–388.

Correia, V.F., Riding, J.B., Fernandes, P., Duarte, L.V., Pereira, Z., 2017. The palynology of the lower and middle Toarcian (Lower Jurassic) in the northern Lusitanian Basin, western Portugal. Review of Palaeobotany and Palynology 237, 75–95.

Couper, R.A., 1958. British Mesozoic microspores and pollen grains. A systematic and stratigraphic study. Palaeontographica Abteilung B 103, 75–179.

Courtinat, B., Algouti, A., 1985. Caractérisation probable du Sinémurien près de Telouat (Haut-Atlas, Maroc): datation palynologique. Geobios 18, 857–867.

Courtinat, B., Malartre, F., Giraud, F., 1998. Le Rhétien en région lyonnaise : analyse palynologique. Geologie France 1, 3–19.

Cranwell, L.M., Srivastava, S.K., 2009. An early Cretaceous (Hauterivian) spore-pollen assemblage from Southern Chile. Palynology 33, 241–280.

Davies, E.H., 1985. The miospore and dinoflagellate cyst Oppel-zonation of the Lias of Portugal. Palynology 9, 105–132.

Dettmann, M.E., 1963. Upper Mesozoic microfloras from southeastern Australia. Proceedings of the Royal Society of Victoria 77, 1–148.

Feist-Burkhardt, S., Heunisch, C., Luppold, F.W., 2009. Überlegungen zur Biostratigraphie und Fazies des "Polyplocus-Sandsteins" (Mittlerer Jura) an der ICE-Trasse östlich Braunschweig. Berliner paläobiologische Abhandlungen 10, 129–149.

Filatoff, J., 1975. Jurassic palynology of the Perth Basin, Western Australia. Palaeontographica Abteilung B 154, 1–113.

Filatoff, J., Price, P.L., 1988. A pteridacean spore lineage in the Australian Mesozoic. Memorial Association Australas. Palaeontologists 5, 89–124.

Fisher, M.J., Bujak, J., 1975. Upper Triassic palynofloras from arctic Canada. Geoscience Man 11, 87–94.

Francis, J.E., 1983. The dominant conifer of the Jurassic Purbeck formation, England. Palaeontology 26, 277–294.

Gedl, P., Ziaja, J., 2012. Palynofacies from Bathonian (Middle Jurassic) ore-bearing clays at Gnaszyn, Kraków-Silesia Homocline. Poland, with special emphasis on sporomorph eco-groups. Acta Geologica Polonica 62, 325–349.

Goryacheva, A.A., 2011. Palynostratigraphy of the lower-middle Jurassic deposits, borehole section Vostok 4 (Southeast of West Siberia). Stratigraphy Geological Correlation 19, 268–288.

Guignard, G., Wang, Y., Ni, Q., Tian, N., Jiang, Z., 2009. A dipteridaceous fern with *in situ* spores from the Lower Jurassic in Hubei, China. Review of Palaeobotany and Palynology 156, 104–115.

Haddoumi, H., Allain, R., Meslouh, S., Metais, G., Monbaron, M., Pons, D., Rage, J.C., Vullo, R., Zouhri, S., Gheerbrant, E., 2016. Guelb el Ahmar (Bathonian, Anoual Syncline, eastern Morocco): first continental flora and fauna including mammals from the Middle Jurassic of Africa. Gondwana Research 29, 290–319.

Harris, T.M., 1937. The fossil flora of Scoresby Sound East Greenland. Part 5: stratigraphic relations of the plant bed. Meddelelser om Grønland 112, 1–114.

Harris, T.M., 1961. The Yorkshire Jurassic Flora. I. Tallophyta-Pteridophyta. Trustees of the British Museum (Natural History), London, 212 p.

Harris, T.M., 1979. The Yorkshire Jurassic flora V. *Coniferales*. British Museum (Natural History), London,167 p.

Hashemi-Yazdi, F., Sajjadi, F., Dehbozorgi, A., 2015. A new lycophyte miospore species from the Middle Jurassic of Iran. Revista Brasileira de Paleontologia 18, 251–260.

Hesselbo, S.P., Coe, A.L., Batten, D.J., Wach, G.D., 1990. Stratigraphic relations of the Lower Greensand (Lower Cretaceous) of the Calne area, Wiltshire. Proceedings of the Geologists' Association 101, 265–278.

Hoelstad, T., 1985. Palynology of the uppermost Lower to Middle Jurassic strata on Bornholm, Denmark. Bulletin of the Geological Society of Denmark 34, 111–132.

Huang, P., 2000. Discovery of middle Jurassic palynological assemblage from Beixiangshan of Nanjing. Acta Micropalaeontologica Sinica 17, 457–469 [In Chinese with English abstract].

Huang, Q.S., 1983. The Early Jurassic Xiangshan Flora from the Yangzi River Valley in Anhui Province, eastern China. Earth Sciences. Journal of Wuhan College of Geology 2, 25–36 [In Chinese with English abstract].

Huang, Q.S., 1988. Vertical diversities of early Jurassic plant fossils in the Middle-Lower Changjiang Valley. Geological Review 34, 193–202 [In Chinese with English abstract].

Huang, W., Sun, C.L., Wang, H.S., Na, Y.L., Li, Y.F., Li, T., 2016. New *Phoenicopsis* leaves (Czekanowskiales) from the Middle Jurassic Daohugou Biota, China and their roles in phytogeographic and paleoclimatic reconstruction. Palaeoworld 25, 388–398.

Ied, I.M., Lashin, G.M., 2016. Palynostratigraphy and paleobiogeography of the Jurassic-Lower Cretaceous succession in Kabrit-1 well, northeastern Egypt. Cretaceous Research 58, 69–85.

Ilyina, V.I., 1986. Subdivision and correlation of the marine and non-marine Jurassic sediments in Siberia based on palynological evidence. Review of palaeobotany and palynology 48, 357–364.

Jiang, D.X., Wang, Y.D., Robbins, E.I., Wei, J., Tian, N., 2008. Mesozoic non-marine petroleum source rocks determined by palynomorphs in the Tarim Basin Xinjiang, northwestern China. Geological Magazine 145, 868–885.

Ju, K.X., 1987. Subdivision of the lower and middle Jurassic deposits in southern Jiangsu. Bulletin of Nanjing Institute of Geology and Mineral Resources. Chinese Academy of Geological Sciences 8, 33–44 [In Chinese with English abstract].

Kemp, E.M., 1970. Aptian and Albian miospores from Southern England. Palaeontographica Abteilung B 131, 73–143.

Koppelhus, E.B., 1991. Palynology of the Lower Jurassic Røsnne formation on Bornholm eastern Denmark. Bulletin of the Geological Society of Denmark 39, 91–109.

Koppelhus, E.B., 1992. Palynologisk underssgelse af nedre jurassiske sedimenter i Anholt-4 boringen. Dansk Geologisk Forening Årsskrift for 1990–91. 73–78.

Koppelhus, E.B., Hansen, C.F., 2003. Palynostratigraphy and palaeoenvironment of the Middle Jurassic Sortehat Formation (Neill Klinter Group), Jameson Land, East Greenland. The Jurassic of Denmark and Greenland. Geological Survey of Denmark and Greenland Bulletin 1, 777–811.

Koppelhus, E.B., Nielsen, L.H., 1994. Palynostratigraphy and palaeoenvironments of the Lower to Middle Jurassic Bagå Formation of Bornholm, Denmark. Palynology 18, 139–194.

Kürschner, W.M., Herngreen, G.W., 2010. Triassic palynology of central and northwestern Europe: a review of palynofloral diversity patterns and biostratigraphic subdivisions, 334, Special Publications, Geological Society, London, pp. 263–283.

Larsson, L.M., 2009. Palynostratigraphy of the Triassic-Jurassic transition in southern Sweden. GFF 131, 147–163.

Legrand, J., Pons, D., Nishida, H., Yamada, T., Choshi Group, Outer Zone of south-west Japan, 2011. Barremian palynofloras from the Ashikajima and Kimigahama formations (Choshi Group, Outer Zone of south-west Japan). Geodiversitas 33, 87–135.

Li, L.Q., Wang, Y.D., 2016. Late Triassic palynofloras in the Sichuan Basin, South China: synthesis and perspective. Palaeoworld 25, 212–238.

Li, Y.Y., Li, J., Chu, S., 1935. Geology of the Nanjing-Zhengjiang Hills. Bulletin of Geological Survey of China 11, 24–62.

Lindström, S., Erlström, M., 2006. The late Rhaetian transgression in southern Sweden: Regional (and global) recognition and relation to the Triassic-Jurassic boundary. Palaeogeography Palaeoclimatology Palaeoecology 241, 339–372.

Lindström, S., Erlström, M., 2007. Dating and correlating potential aquifers for geothermal energy, CO2, and energy storage, within the late Triassic-early Cretaceous succession in the Swedish part of the Danish Basin. , [Available from: www.sgu.se/dokument/fou_extern/Lindstrom_Erlstrom.pdf]

Liu, J., Zhao, J., 1924. Geology of Jiangsu. Geological Bulletin Series A 4.

Pedersen, K.R., 1985. Palynology of the marine Jurassic formations in the Vardekløft ravine, Jameson Land, East Greenland. Geological Society of Denmark. Bull. 33, 371–400.

Mahmoud, M.S., Moawad, A.R.M., 2000. Jurassic-Cretaceous (Bathonian to Cenomanian) palynology and stratigraphy of the West Tiba-1 borehole, northern Western Desert Egypt. Journal of African Earth Sciences 30, 401–416.

Mander, L., 2011. Taxonomic resolution of the Triassic-Jurassic sporomorph record in East Greenland. Journal of Micropalaeontology 30, 107–118.

Mander, L., Kürschner, W.M., McElwain, J.C., 2010. An explanation for conflicting records of Triassic-Jurassic plant diversity. Proceedings of the National Academy of Sciences of the United States of America 107, 15351–15356.

Martínez, M.A., Prámparo, M.B., Quattrocchio, M.E., Zavala, C.A., 2010. Depositional environments and hydrocarbon potential of the Middle Jurassic Los Molles Formation, Neuquén Basin, Argentina: palynofacies and organic geochemical data. Andean Geology 35, 279–306.

Martínez, M.A., García, W.M., Quattrocchio, M.E., 1999. Análisis palinofacial aplicado a cortejos sedimentarios del Jurásico Medio en el sector Suroccidental de la cuenca neuquina, Argentina. Revista Española de Paleontología 14, 217–230.

Morbey, S.J., Dunay, R.E., 1978. Early Jurassic to Late Triassic dinoflagellate cysts and miospores. In: Thusu, B. (Ed.), Distribution of Biostratigraphically diagnostic dinoflagellate cysts and miospores from the Northwest European continental shelf and adjacent areas., 100, Continental Shelf Institute Publication, pp. 4–59.

Nielsen, O.B., Seidenkrantz, M.S., Abrahamsen, N., Schmidt, B.J., Koppelhus, E.B., Ravn-Sørensen, H., Korsbec, U., Nielsen, K.G., 2003. The Lower-Middle Jurassic of the Anholt borehole: implications for the geological evolution of the eastern margin of the Danish Basin. Geological Society of Denmark Bulletin 1, 585–609.

Ogg, J.G., Ogg, G., Gradstein, F.M., 2016. A Concise Geologic Time Scale: 2016. Elsevier, Amsterdam, Netherlands.

Orlowska-Zwolinska, T., 1983. Palynostratigraphy of the upper part of triassic epicontinental sediments in Poland, palinostratygrafia epikontynentalnych osadów wyższego triasu w Polsce. Prace Instytutu Geologicznego 104, 1–89 [In Polish with English abstract].

Osborn, J.M., Taylor, T.N., 1993. Pollen morphology and ultrastructure of the Corystospermales: permineralized *in situ* grains from the Triassic of Antarctica. Review of Palaeobotany and Palynology 79, 205–219.

Palliani, R.B., 1997. Toarcian sporomorph assemblages from the Umbria-Marche basin, central Italy. Palynology 21, 105–121.

Palliani, R.B., Riding, J.B., 2000. A palynological investigation of the Lower and lowermost Middle Jurassic strata (Sinemurian to Aalenian) from North Yorkshire, UK. Proceedings of the Yorkshire Geological Society 53, 1–16.

Pedersen, K.R., Crane, P.R., Friis, E.M., 1989. Pollen organs and seeds with Eucommiidites pollen. Grana 28, 279–294.

Philippe, M., Thevenard, F., Barale, G., Ferry, S., Guignard, G., 1998. Middle Bathonian floras and phytocoenoses of France. Palaeogeography, Palaeoclimatology. Palaeoecology 143, 135–158.

Potonié, R., 1967. New phylogenetic facts on fossil spores. Review of Palaeobotany and Palynology 1, 75–82.

Richthofen, F.F., 1912. Das südöstliche China. Allgemeine Übersicht. In: Tiessen, E. (Ed.), Ergebnisse eigener Reisen und darauf gegründeter Studien, 3, Verlag von Dietrich Reimer (Ernst Vohsen), pp. 395–753.

Riding, J.B., 1984. A palynological investigation of Toarcian to early Aalenian strata from the Blea Wyke area, Ravenscar, North Yorkshire. Proceedings of the Yorkshire Geological Society 45, 109–122.

Riding, J.B., Westermann, G.E., Darbyshire, D.F., 2010. New evidence for the age of the Athol Formation (Middle Jurassic; Bajocian) in the Tusk-1 and Tusk-2 wells, offshore Carnarvon Basin, Western Australia. Alcheringa 34, 21–35.

Riding, J.B., Walton, W., Shaw, D., 1991. Toarcian to Bathonian (Jurassic) palynology of the Inner Hebrides, northwest Scotland. Palynology 15, 115–179.

Sajjadi, F., Hashemi, H., Dehbozorgi, A., 2008. Middle Jurassic palynomorphs of the Kashafrud Formation, Koppeh Dagh Basin, Northeastern Iran. Micropaleontology 53, 391–408.

Schnyder, J., Pons, D., Yans, J., Tramoy, R., Abdulanova, S., 2016. Integrated stratigraphy of a continental Pliensbachian-Toarcian Boundary (Lower Jurassic) section at Taskomirsay, Leontiev Graben, southwest Kazakhstan, Geological Society. 427, Special Publications, London, pp. 337–356.

Seidenkrantz, M.S., Koppelhus, E.B., Ravn-Sørensen, H., 1993. Biostratigraphy and palaeoenvironmental analysis of a Lower to Middle Jurassic succession on Anholt, Denmark. Journal of Micropalaeontology 12, 201–218.

Slater, S.M., Wellman, C.H., 2015. A quantitative comparison of dispersed spore/pollen and plant megafossil assemblages from a Middle Jurassic plant bed from Yorkshire, UK. Paleobiology 41, 640–660.

Slater, S.M., Wellman, C.H., 2016. Middle Jurassic vegetation dynamics based on quantitative analysis of spore/pollen assemblages from the Ravenscar Group, North Yorkshire, UK. Palaeontology 59, 305–328.

Srivastava, S.K., 2011. Spore-pollen biostratigraphy of the English Jurassic. Palaeontographica Abteilung B 285, 113–201.

Sze, H.C., 1931. Beiträge zur Liassische Flora von China. Memoirs of Nanjing Institute of Geology, 12pp. 1–85 [Memoirs Nanjing Institute of Geology].

Sze, H.C., 1956. The fossil flora of the Mesozoic oil-bearing deposits of the Dzungaria-Basin, northwestern Sinkiang. Acta Palaeontologica Sinica 4, 470–484.

Townrow, J.A., 1960. The Peltaspermaceae, a pteridosperm family of Permian and Triassic age. Palaeontology 3, 333–361.

Tralau, H., 1968. Evolutionary trends in the genus Ginkgo. Lethaia 1, 63–101.

Tramoy, R., Schnyder, J., Tu, T.N., Yans, J., Jacob, J., Sebilo, M., Derenne, S., Phillippe, M., Huguet, A., Pons, D., Baudin, F., 2016. The Pliensbachian-Toarcian paleoclimate transition: new insights from organic geochemistry and C, H, N isotopes in a continental section from Central Asia. Palaeogeography, Palaeoclimatology. Palaeoecology 461, 310–327.

Traverse, A., 2007. Paleopalynology, second edition. Springer, Netherlands813.

Turner, S., Bean, L.B., Dettmann, M., McKellar, J.L., McLoughlin, S., Thulborn, T., 2009. Australian Jurassic sedimentary and fossil successions: current work and future prospects for marine and non-marine correlation. GFF 131, 49–70.

Vajda, V., 2001. Aalenian to Cenomanian terrestrial palynofloras of SW Scania, Sweden. Acta Palaeontologica Polonica 46, 403–426.

Vajda, V., Calner, M., Ahlberg, A., 2013. Palynostratigraphy of dinosaur footprint-bearing deposits from the Triassic-Jurassic boundary interval of Sweden. GFF 135, 120–130.

Vakhrameev, V.A., 1991. Jurassic and Cretaceous floras and climates of the Earth. Cambridge University Press, Cambridge, UK, 318 p.

Van Erve, A.W., Besems, R.E., Love, C.F., 1988. A palynological investigation of some Lower Kimmeridgian deposits from Spain. Journal of Micropalaeontology 7, 217–232.

Van Konijnenburg-Van Cittert, J.H., 1971. *In situ* gymnosperm pollen from the Middle Jurassic of Yorkshire. Acta Botanica Neerlandica 20, 1–96.

Van Konijnenburg-Van Cittert, J.H., 1978. Osmundaceous spores *in situ* from the Jurassic of Yorkshire, England. Review of Palaeobotany and Palynology 26, 125–141.

Van Konijnenburg-Van Cittert, J.H., 1981. Schizaeaceous spores *in situ* from the Jurassic of Yorkshire, England. Review of Palaeobotany and Palynology 33, 169–181.

Van Konijnenburg-Van Cittert, J.H., 1989. Dicksoniaceous spores *in situ* from the Jurassic of Yorkshire, England. Review of Palaeobotany and Palynology 61, 273–301.

Van Konijnenburg-Van Cittert, J.H., 1991. Diversification of spores in fossil and extant *Schizaeaceae*. Pollen and Spores. Patterns of diversification systematics association special volume, 44, pp. 103–118.

Van Konijnenburg-Van Cittert, J.H., 1992. An enigmatic Liassic microsporophyll, yielding Ephedripites pollen. Review of Palaeobotany and Palynology 71, 239–254.

Van Konijnenburg-Van Cittert, J.H., 1993. A review of the Matoniaceae based on *in situ* spores. Review of Palaeobotany and Palynology 78, 235–267.

Van Konijnenburg-Van Cittert, J.H., 2002. Ecology of some late Triassic to early Cretaceous ferns in Eurasia. Review of Palaeobotany and Palynology 119, 113–124.

Van Konijnenburg-Van Cittert, J.H., Van der Burgh, J., 1989. The flora from the Kimmeridgian (Upper Jurassic) of Culgower, Sutherland, Scotland. Review of Palaeobotany and Palynology 61, 1–51.

Vijaya, 2000. Palynology of the Jurassic-Cretaceous transition in the Rajmahal Formation, 24, Alcheringa, West Bengal, India, pp. 125–133.
Wan, X.D., 1987. The Middle and Lower Jurassic of the Anqing region. Journal of Stratigraphy 11, 187–193 [In Chinese with English abstract].
Wang, G.P., Chen, Q.S., Li, Y.T., Li, H.M., Guo, S.X., Lan, S.X., Ju, K.X., 1982. Plant kingdom. In: Palaeontological atlas of Eastern China. III. Volume of mesozoic and cenozoic. Geological Publishing House, Beijing, pp. 236–336, [In Chinese with English abstract].
Wang, Y., Cao, Z., Thévenard, F., 2005. Additional data on *Todites* (Osmundaceae) from the lower Jurassic with special references to the paleogeographical and stratigraphical distributions in China. Geobios 38, 823–841.
Wang, Y., Guignard, G., Lugardon, B., Barale, G., 2001. Ultrastructure of *in situ* Marattia asiatica (Marattiaceae) spores from the lower jurassic in Hubei, China. International Journal of Plant Sciences 162, 927–936.
Yao, C., 2000. Some specimens of gymnospermae from the lower part of Xiangshan group in Jiangsu and Anhui Provinces with study on their cuticules. Acta Palaeontologica Sinica 39, 334–342 [In Chinese with English abstract].
Ziaja, J., 2006. Lower Jurassic spores and pollen grains from Odrowąż, Mesozoic margin of the Holy Cross Mountains, Poland. Acta Palaeobotanica 46, 3–83.