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开鲁盆地钱家店凹陷早白垩世义县组孢粉组合及其古气候演变

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摘要: 研究白垩纪植物演替与气候变化对认识现今生态环境形成过程与演变具有重要意义。开鲁盆地义县组孢粉学的研究不仅丰富了该地区早白垩世孢粉学资料, 也为该地区早白垩世地层划分与对比提供了依据。通过对开鲁盆地东北部钱家店凹陷钻孔 QIV-65-136 底部泥岩样品分析, 获得了丰富的孢粉化石, 并建立了 *Cyathidites-Pinuspollenites-Protoconiferus* 组合。根据典型分子时代分布、重要种属含量上的变化及横向组合对比, 确定其地质时代为早白垩世早期, 层位相当于义县组。孢粉植物群反映的植被景观为在湖盆的周围山地生长着松科高大乔木, 伴有罗汉松科、杉科及少量苏铁科、南美杉科、掌鳞杉科等植物, 林下、湖岸地区生长着桫欏科、紫萁科及莎草蕨科等蕨类植物。整体面貌以针叶植物为主, 所处的气候环境为湿润的暖温带—亚热带。

关键词: 早白垩世; 义县组; 孢粉组合; 古气候; 矿产勘查工程; 开鲁盆地; 钱家店凹陷; 辽宁
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Early Cretaceous spore and pollen assemblage from the Yixian Formation in the Qianjiadian Depression of Kailu Basin and its paleoclimate evolution

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Abstract: The study of plant succession and climate change in Cretaceous is of great significance for the understanding of formation and evolution of the present ecological environment. The study on the palynology from the Yixian Formation can provide palynology data and lay the basis on Early Cretaceous stratigraphic classification and correlation in the northeastern area of Kailu

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basin. Based on the analysis of sporo-pollen fossils of 47 species from 39 genera recognized from the bottom of well QIV-65-136 in the Qianjiadian depression, Kailu Basin, the *Cyathidites-Pinuspollenites-Protoconiferus* assemblage was established. According to the age range of typical species, content change on key species and horizontal contrast, this assemblage should be dated as the early Early Cretaceous, the horizon is equivalent to the Yixian Formation. The palynoflora shows the Coniferales plants on the high elevation mountain around the lake, accompanied by Podocarpaceae, Taxodiaceae, Cycadaceae, Araucariaceae and Cheirolepidiaceae plants, the fern such as Osmundaceae, Cyatheaceae, Schizaeaceae plants growing under the trees near the lake. Vegetation is occupied by coniferous, representing a humid temperate to subtropical zone.

Key words: Early Cretaceous; Yixian Formation; Sporo-pollen assemblage; paleoclimate; mineral exploration engineering; Kailu Basin; Qianjiadian Depression; Liaoning

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1 引言

白垩纪(145~65 Ma)因其全球海平面(Haq et al., 1987; Stoll and Schrag, 1996; Miller et al., 2005)、大气CO₂及平均温度均比现今高而被认为是距今最近、跨越时间最长的典型“温室地球”时期(Herman and Spicer, 1996; Berner and Kothavala, 2001; Gradstein et al., 2004; Keller, 2008; 杜宝霞等, 2010; Crowley and Kim, 2013),研究白垩纪生态环境对认识现今环境格局的形成及未来演变具有重要的参考价值。松辽盆地是白垩纪陆相沉积地层发育的地区,蕴含大量典型的古生物化石,是研究早白垩世陆相古气候和古环境变化、生物演化的重要地区(Chen and Chang, 1994; Feng et al., 2010; Deng et al., 2013; 张德军等, 2019; 白静等, 2020; 商斐等, 2020; 徐增连等, 2021)。

义县组岩性为一套基性—中基性—中性—中酸性陆相火山喷发岩系,在其喷发活动间歇期形成了7个规模不等的河湖相沉积夹层,以产出大量精美的热河生物群珍稀化石而闻名于世。从20世纪20年代至今,已有众多的古生物学家对义县组做了大量的研究工作,如生物大化石(Hou et al., 1995; 季强和姬书安, 1996, 1997; 汪筱林等, 1998)、孢粉化石(张立君等, 1985; 中国地质科学院地质研究所地层组, 1989; Li and Liu, 1994; 丁秋红等, 2003a, b; 丁秋红和张立东, 2004; Li and Batten, 2007; 黎文本, 2010; 崔莹等, 2015)和古气候学等(王思恩, 1999; 丁秋红等, 2003a, b; 闫义等, 2003; 丁秋红和张立东,

2004)。然而关于义县组的研究仍存在几个重要的问题:(1)研究区域局限,仅集中在辽西地区;(2)义县组的时代是晚侏罗世还是早白垩世一直存在争论,目前主要有晚侏罗世(王思恩, 1998)、早白垩世(李佩贤等, 1993)、晚侏罗世—早白垩世(王五力等, 2003)以及晚白垩世(孙肖等, 2017)四种观点;(3)前人的研究大多集中在生物大化石方面,孢粉微体化石方面研究虽在早期取得了一定成果,但近年来鲜有数据更新和更深入研究,因此数据稍显不足。本文通过对开鲁盆地钱家店地区义县组孢粉化石的鉴定和分析,精确划分孢粉化石组合及特征,推断其地层时代,同时探讨植被类型和古气候演化趋势,对本地区生物地层研究及与邻区对比具有十分重要的意义。

2 区域地质与地层概况

开鲁盆地位于松辽盆地西南部,面积约3.32×10⁴ km²,是中国北方较大型中生代盆地。自南东向北西依次由哲东南隆起、哲中拗陷、舍伯吐隆起、陆家堡拗陷和西缘斜坡5个二级构造单元构成。钱家店凹陷位于开鲁盆地东北部,属于哲东南隆起的次级负向构造单元,呈NNE向窄条状展布,面积约为1280 km²(图1a),是砂岩型铀矿勘探的重点区块(汤庆四等, 2016)。开鲁盆地以前震旦纪花岗片麻岩和石炭纪—二叠纪变质岩系为基底,盖层发育的主要阶段是白垩纪,其累计最大厚度达10 km。

开鲁盆地白垩纪地层的研究工作始于20世纪50年代后期。60—70年代中华人民共和国地质矿

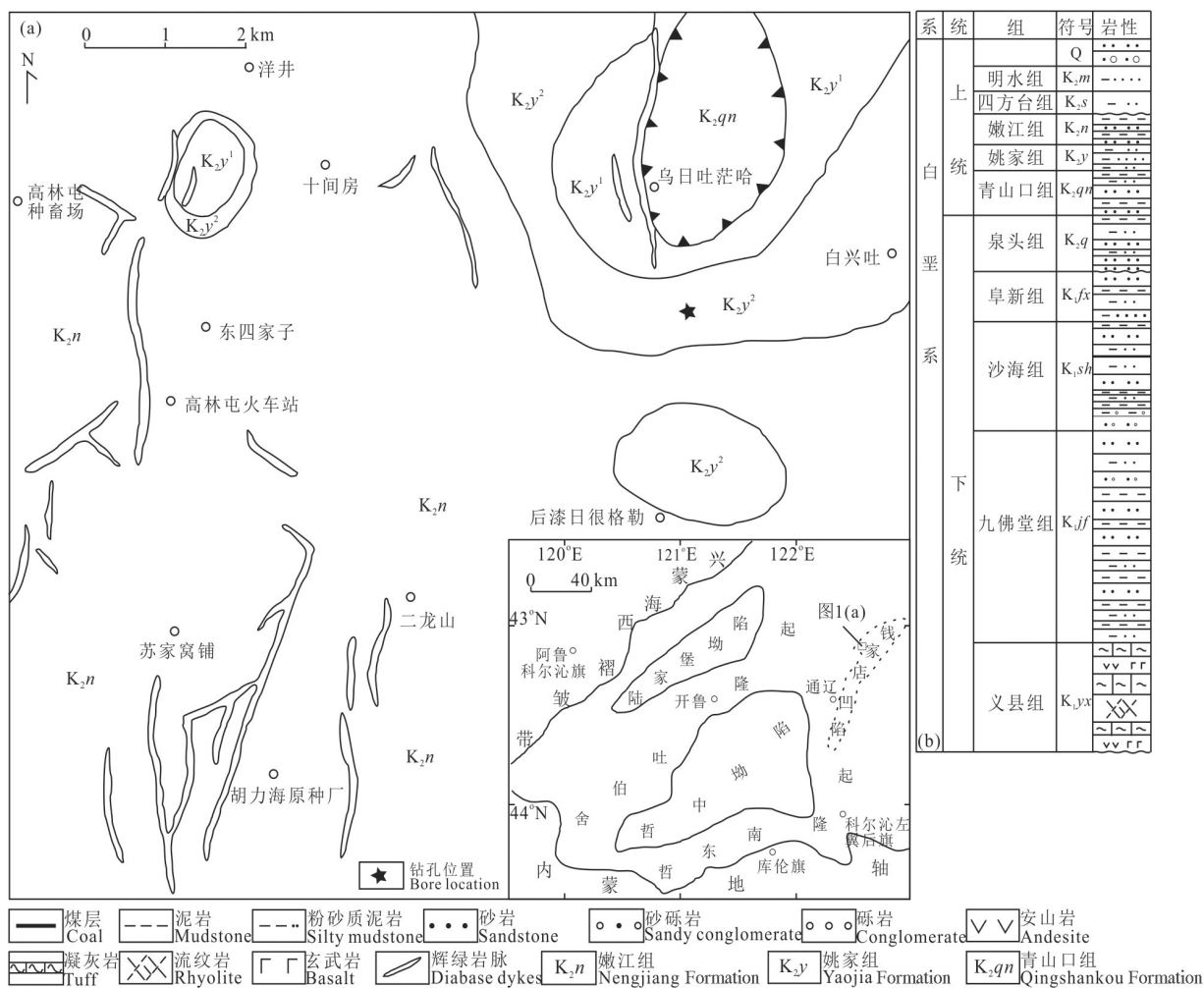


图1 研究区地质略图(a, 据罗毅等, 2012; 荣辉等, 2016修改)与地层综合柱状图(b, 据陈为佳等, 2014修改)

Fig.1 Geological map (a, modified from Luo et al., 2012; Rong et al., 2016) and comprehensive column (b, modified from Chen et al., 2014) of the study area

产部、吉林石油集团、大庆油田勘探开发研究院等先后在该地区开展的物化探及浅孔钻探工作, 揭示了上白垩统地层序列。20世纪80年代以来, 辽河石油勘探局先后在开鲁盆地开展了大面积的地球物理勘探和数十口深井钻探, 探明了下白垩统地层序列, 并在其中获得了丰富的早白垩世生物地层方面的宝贵资料。许坤等(1995)综合利用古生物、钻井、地震剖面和古地磁资料, 建立了开鲁盆地晚中生代地层层序, 这一成果被后人广泛采用; 此后相继又有很多学者(王仁厚等, 1999; 陈丕基, 2000; 孙革和郑少林, 2000; 吴炳伟, 2007)对区内的地层进行了研究。盆地内晚白垩世生物地层特征与松辽盆地同时期地层一致; 早白垩世地层则更接近开鲁盆地南部辽西阜新盆地生物地层特征, 尤其见有标准的热河生物群化石, 据此, 辽河油田直接采用了

辽西地区地层名称。区内白垩纪地层自下而上依次包括下白垩统义县组(K_{2yx})、九佛堂组(K_{2jf})、沙海组(K_{2sh})、阜新组(K_{2fx})和泉头组(K_{2q})以及上白垩统青山口组(K_{2qn})、姚家组(K_{2y})、嫩江组(K_{2n})、四方台组(K_{2s})、明水组(K_{2m}) (图1b)。地层中化石丰富, 已发现了介形类、腹足类、双壳类、孢粉、沟鞭藻、鱼类、轮藻、叶肢介等8个门类的化石(吴炳伟, 2006, 2007)。本文报道的孢粉材料主要取自钱家店凹陷钻孔QIV-65-136, 通过对其孢粉组合特征和古气候进行了探讨, 为本区地层划分对比、时代归属及生物群演化提供了重要的参考材料。

3 研究材料与方法

本文研究的孢粉化石材料取自钱家店凹陷QIV-65-136井底部(深度411.5~389.4 m)灰、黑色

泥岩和粉砂质泥岩层中(图2),共采集样品4块。孢粉化石的处理和鉴定委托中国科学院南京地质古生物研究所卢辉楠研究员团队完成。孢粉分析方法采用盐酸-氢氟酸处理法。具体操作步骤:(1)取20~50 g样品,在研钵中研磨至粒径为小于0.5 mm的颗粒;(2)用体积浓度10%的稀盐酸浸泡(稍淹没样品),充分搅拌,去除钙质;(3)加满清水,静置3~4 h,洗至中性;(4)徐徐加入250 mL氢氟酸,充分搅拌,放置5~7 d;(5)加水,洗至中性;(6)过筛(180 μm),去除大颗粒,沉淀;(7)留300 mL左右放入离心杯,离心去水(3000 r/5 min);(8)加浓盐酸(一般150 mL),置于电炉上加热(2 h),至样品漂浮或液体澄清;(9)加水水洗2次,至中性;(10)洗样:重液分离和过筛法。对化石丰富的样品,通常至少统计150粒,大多>200粒;相对丰富的样品则统计到100

粒,含量较少的样品则通过增加玻片数达到统计数量。化石鉴定统计和照相都在Zeiss Axio Scope A1显微镜下进行。

4 孢粉组合面貌

4块样品中的孢粉化石及其百分含量见表1。

4.1 孢粉化石组合

通过对钱家店凹陷QIV-65-136井4件孢粉样品处理、分析和鉴定,每块样品中均发现了丰富的孢粉化石(表1,图3),共计39属47种。组合中裸子植物花粉含量最高,占整个组合的57.11%~91.73%,平均75.05%。裸子植物花粉中以松科的新型双气囊花粉为主,比如*Abietinaepollenites/Pinuspollenites*含量突出,为7.59%~60.0%,平均29.91%,其他具气囊花粉如*Cedripites*(0~3.16%),*Piceapollenites*(0~

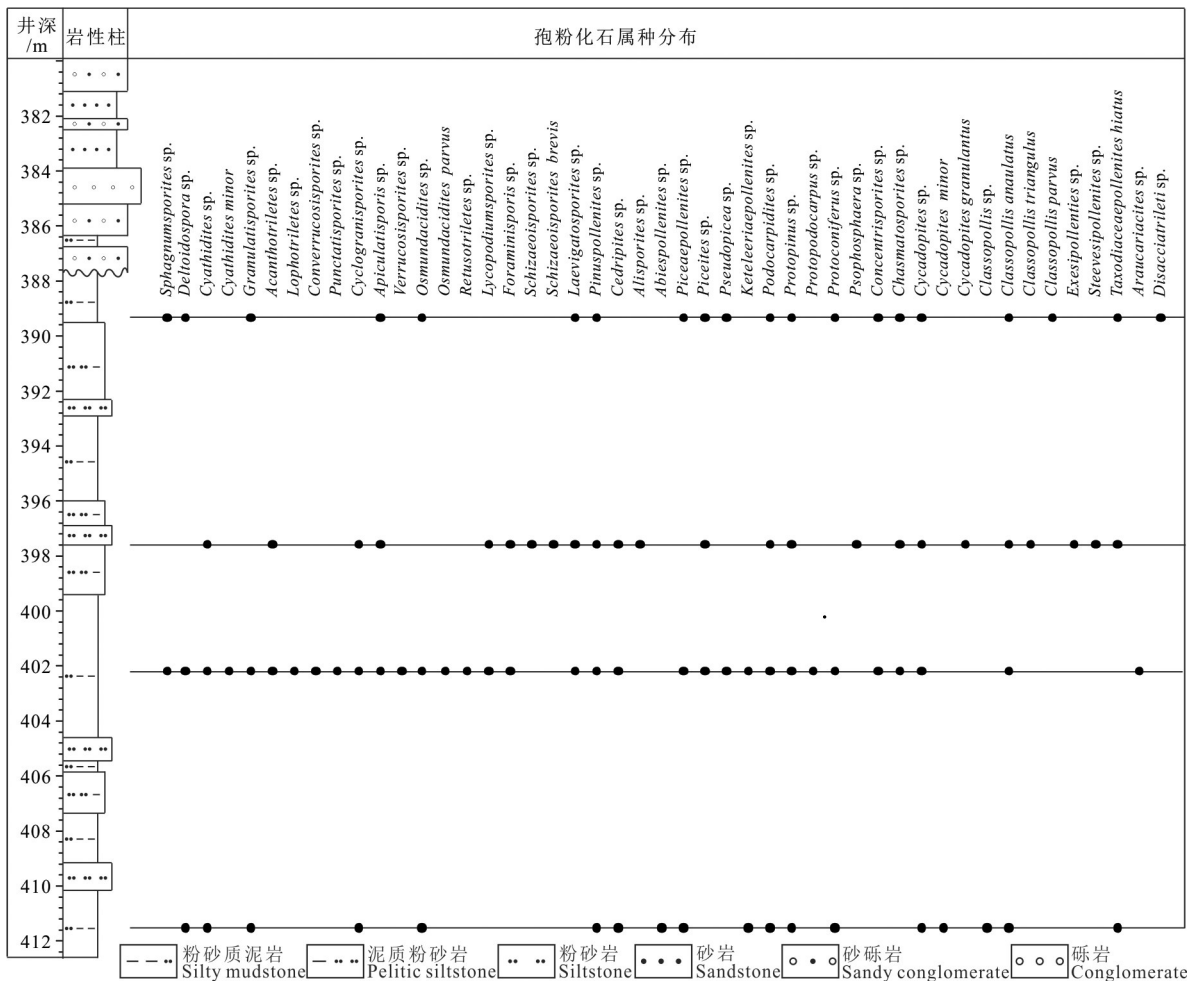


图2 开鲁盆地钱家店凹陷QIV-65-136井孢粉化石分布
Fig.2 Distribution of spores and pollen from well QIV-65-136 in Qianjiadian depression

表1 开鲁盆地钱家店凹陷QIV-65-136井下白垩统孢粉化石百分含量统计

Table 1 Statistics of the Lower Cretaceous spores and pollen from well QIV-65-136 in Qianjiadian depression

孢粉种类	井深/m			
	389.4	397.6	402.2	411.5
蕨类植物孢子	8.27	32.28	42.89	16.36
<i>Sphagnumsporites</i> sp.	0.75	0	0.71	0
<i>Deltoidospora</i> sp.	2.26	0	1.42	2.42
<i>Cyathidites</i> sp.	0	6.96	17.06	10.91
<i>C. minor</i>	0	0	4.50	0
<i>Acanthotriletes</i> sp.	0	1.27	0.47	0
<i>Granulatisporites</i> sp.	0.75	0	1.18	1.21
<i>Lophotriletes</i> sp.	0	0	0.47	0
<i>Converrucosisporites</i> sp.	0	0	0.47	0
<i>Punctatisporites</i> sp.	0	0	0.24	0
<i>Cyclogranisporites</i> sp.	0	1.90	0.71	1.21
<i>Apiculatisporis</i> sp.	0.75	1.27	0.71	0
<i>Verrucosisporites</i> sp.	0	0	0.95	0
<i>Osmundacidites</i> sp.	3.01	0	6.87	0.61
<i>O. parvus</i>	0	0	2.84	0
<i>Retusotriletes</i> sp.	0	0	0.24	0
<i>Lycopodiumsporites</i> sp.	0	0.63	2.61	0
<i>Foraminisporis</i> sp.	0	2.53	1.18	0
<i>Schizaeoisporites</i> sp.	0	11.39	0	0
<i>S. brevis</i>	0	0.63	0	0
<i>Laevigatosporites</i> sp.	0.75	5.70	0.24	0
裸子植物花粉	91.73	67.72	57.11	83.64
<i>Pinuspollenites</i> sp.	28.57	7.59	23.46	60
<i>Cedripites</i> sp.	0	3.16	0.24	2.42
<i>Alisporites</i> sp.	0	4.43	0	0
<i>Abiespollenites</i> sp.	0	0	0	0.61
<i>Piceapollenites</i> sp.	3.01	0	2.37	5.45
<i>Piceites</i> sp.	3.01	5.06	0.95	0
<i>Pseudopicea</i> sp.	3.76	0	4.03	0
<i>Keteleeriaepollenites</i> sp.	0	0	0.95	1.21
<i>Podocarpidites</i> sp.	3.01	3.16	2.61	1.21
<i>Protopinus</i> sp.	2.26	0.63	6.16	1.21
<i>Protopodocarpus</i> sp.	0	0	0.24	0
<i>Protoconiferus</i> sp.	26.32	0	9.48	2.42
<i>Psophosphaera</i> sp.	0	11.39	0	0
<i>Concentrisporites</i> sp.	0.75	0	0.24	0
<i>Chasmatosporites</i> sp.	1.50	3.80	0.71	0
<i>Cycadopites</i> sp.	9.77	8.86	4.98	0.61
<i>C. minor</i>	0	0	0	1.82
<i>C. granulatus</i>	0	0.63	0	0
<i>Classopollis</i>	0	0	0	3.03
<i>C. annulatus</i>	1.50	1.27	0.47	1.82
<i>C. triangulus</i>	0	0.63	0	0
<i>C. parvus</i>	0.75	0	0	0
<i>Exesipollentis</i> sp.	0	1.90	0	0
<i>Steevesipollenites</i> sp.	0	0.63	0	0
<i>Taxodiaceapollenites hiatus</i>	1.50	14.56	0	1.82
<i>Araucariacites</i> sp.	0	0	0.24	0
<i>Disacciatrileti</i>	6.02	0	0	0

5.45%) , *Abiespollenites* (0~0.61%) , *Keteleeriaepollenites* (0~1.21%) , *Podocarpidites* (1.21%~3.16%) 和 *Disacciatrileti* (0~6.02%) ; 其次是气囊与本体分化不好的松柏类以较高含量出现, 为 3.63%~35.35% , 平均 16.38% , 包括 *Protoconiferus* (0~26.32%) , *Protopinus* (0.63%~6.16%) , *Piceites* (0~5.06%) , *Pseudopicea* (0~4.03%) 和 *Protopodocarpus* (0~0.24%) ; 无气囊的松柏类花粉很少, 如 *Taxodiaceapollenites hiatus* 占 0~14.56% , 平均 4.47% , *Psophosphaera* 占 0~11.39% , 平均 2.85% ; 此外, 环沟类花粉如掌鳞杉科的 *Classopollis* , 包括 *C. annulatus* , *C. triangulus* , *C. parvus* 和单沟类花粉如苏铁科的 *Cycadopites* , 包括 *C. minor* , *C. granulatus* 在组合中连续出现, 但含量不占据主导地位。

蕨类植物孢子含量为 8.27%~42.89% , 平均 24.95% 。其中桫欏科的 *Cyathidites* 在蕨类中含量最高, 含量为 6.96%~21.56% , 平均 9.86% , 包括 *C. minor* ; 其次为莎草蕨科的 *Schizaeoisporites* , 含量为 0~12.02% , 平均 3.00% , 所见种主要为 *S. brevis* ; 紫萁科的 *Osmundacidites* 含量为 0~9.71% , 平均 3.33% , 见 *O. parvus* ; 此外, 还有少量 *Sphagnumsporites* , *Deltoidospora* , *Granulatisporites* , *Acanthotriletes* , *Lophotriletes* , *Converrucosisporites* , *Punctatisporites* , *Cyclogranisporites* , *Apiculatisporis* , *Verrucosisporites* , *Retusotriletes* , *Laevigatosporites* , *Lycopodiumsporites* 和 *Foraminisporis* 等, 在组合中连续出现但含量不高。

在本组合中未见被子植物花粉。

4.2 地质时代

上述孢粉化石可称为 *Cyathidites*-*Pinuspollenites*-*Protoconiferus* 组合。 *Protoconiferus* 含量为 0~26.32% , *Cyathidites* 含量为 6.96%~21.56% , *Pinuspollenites* 含量为 7.59%~60.0% , 它们组成当前组合的优势分子。组合特征是裸子植物花粉多于蕨类孢子, 其中具气囊的松柏类花粉很丰富, 含量一般超过 50% , 而无气囊的松柏类花粉不多, 尤其是 *Classopollis* 很少, 最高含量为 4.85% ; 孢子中 *Cyathidites* , *Granulatisporites* , *Osmundacidites* 经常出现; 早白垩世特征分子 *Foraminisporis* 也有一定含量。

Foraminisporis 是白垩纪早期的特征属, 侏罗纪

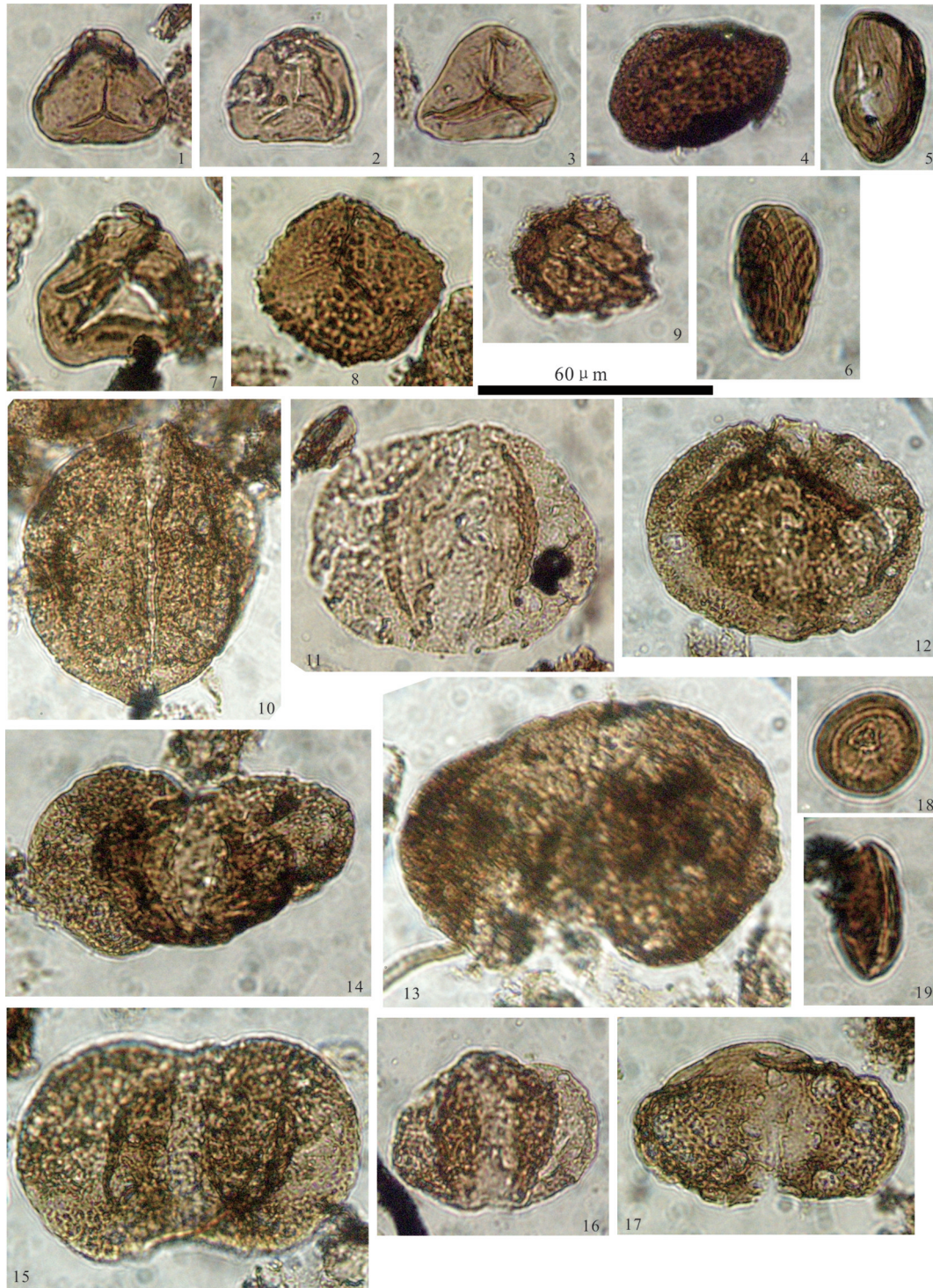


图3 开鲁盆地钱家店凹陷 QIV-65-136 井底部代表性孢粉化石

1~3—三角孢属; 4—紫萁孢属; 5, 6—希指蕨孢属; 7—桫欏孢属; 8—有孔孢属; 9—石松粉属; 10—原始松柏粉属; 11—假云杉粉属; 12—原始松粉属; 13—油杉粉属; 14, 15—罗汉松粉属; 16, 17—松粉属; 18—克拉梭粉属; 19—苏铁粉属

Fig.3 Representative spores and pollen from well QIV-65-136 in Qianjiadian depression

1~3—*Deltoidospora* sp.; 4—*Osmundacidites* sp.; 5, 6—*Schizaeoisporites* sp.; 7—*Cyathidites* sp.; 8—*Foraminisporis* sp.; 9—*Lycopodiumsporites* sp.; 10—*Protoconiferus* sp.; 11—*Pseudopicea* sp.; 12—*Keteleeriaepollenites* sp.; 13—*Podocarpidites* sp.; 14, 15—*Pinuspollenites*; 16, 17—*Pinuspollenites*; 18—*Classopollis* sp.; 19—*Cycadopites* sp.

迄今未见及,最晚延至古近纪。该属最早由 Krutzsch (1959) 在德国下白垩统发现,其后在俄罗斯、蒙古及北美下白垩统均有记录 (Bolkhovitina, 1961), 在我国主要见于早白垩世, 该属是东北地区下白垩统的常见分子 (余静贤, 1986; 中国科学院南京地质古生物研究所, 1986)。

中国晚侏罗世时以耐干旱的掌鳞杉科花粉 *Classopollis* 占统治地位, 通常含量在 50% 以上为其特征 (王思恩等, 1982)。早白垩世, 在中国北方普遍衰落, 即一进入白垩纪转入少量分布 (地质矿产部成都地质矿产研究所, 1983; 天津地质矿产研究所, 1984; 尚玉珂, 1991)。例如: 在内蒙古武川盆地晚侏罗世为 33.0%~76.9%, 早白垩世为 13.0%~24.0% (赵传本, 1987); 在英国南部提塘阶孢粉组合中 *Classopollis* 含量也很高, 它与杉科无口器花粉共占孢粉总和的 70%~90% (Norris, 1977)。本组合中 *Classopollis* 含量较少, 不足 5%, 呈现出中国北方早白垩世特点, 应排除其属于晚侏罗世的可能。

Schizaeoisporites 在世界各地几乎都在白垩纪, 尤其在早白垩世晚期以后大量繁盛, 到古近纪已很少见, 中国晚白垩世早、中期地层中均很丰富 (宋之琛, 1986; 高瑞祺等, 1999)。而在本段中 *Schizaeoisporites* 仅少量或个别出现, 推断本组合应属于早白垩世早中期。

此外, 具气囊的原始松柏类花粉在中国北方地区晚侏罗世和早白垩世早、中期地层中有相当的含量, 早白垩世晚期急剧衰退 (主要指阿普特期和阿尔必期) 至晚白垩世灭绝 (高瑞祺等, 1999), 在本组合中古老松柏类也有较高的含量。从整个孢粉组合来看, 组合中存在一些早白垩世较典型分子, 有些还是较早期类型, 在一些重要属种的含量上, 也呈现出早白垩世较早期特征。综合考虑本组合应属于早白垩世早中期。

4.3 孢粉组合对比

目前, 已有许多学者对开鲁盆地早白垩世孢粉组合特征进行过研究 (李凤霞, 2005; 吴炳伟, 2006)。李凤霞 (2005) 系统研究了开鲁盆地陆家堡坳陷早白垩世阜新组孢粉化石, 建立 *Cicatricosisporites*-*Laevigatosporites*-*Tricolpopollenites* 组合; 吴炳伟 (2006) 通过对开鲁盆地 20 余口探井

1500 余块样品进行分析, 建立了 3 个早白垩世孢粉组合自下而上为九佛堂组 *Cicatricosisporites*-*Concavissimisporites*-*Classopollis* 组合、沙海组 *Cicatricosisporites*-*Abdiverrucospora*-*Piceapollenites* 组合、以及阜新组 *Cicatricosisporites*-*Laevigatosporites*-*Pilosissporites*-*Asteropollis* 组合。王大宁等 (2016) 分析冀北—辽西地区侏罗—白垩纪之交期孢粉植物群的地层分布, 自下而上依次为大北沟组下部 *Piceites*-*Podocarpidites*-*Schizaeoisporites* 组合、大北沟组上部 *Cicatricosisporites*-*Luanpingspora*-*Jugella* 组合、义县组 *Piceapollenites*-*Densoisporites*-*Cicatricosisporites*-*Aequitriradites* 组合、九佛堂组 *Piceapollenites*-*Cicatricosisporites*-*Concavissimisporites* 组合、沙海组 *Liaoxisporites*-*Pilosissporites*-*Classopollis* 组合、阜新组下部 *Pilosissporites*-*Appendicisporites*-*Cicatricosisporites*-*Triporetetes* 组合、阜新组上部 *Deltoidospora*-*Cicatricosisporites*-*Appendicisporites* 组合。认为海金沙科孢子, 尤其是 *Cicatricosisporites* 的含量在大北沟组上部和义县组下部仅少量出现, 从九佛堂组开始, 其含量逐渐增加。本文研究层位的孢粉组合中未出现 *Cicatricosisporites*, 且海金沙科分子类型和含量很少, 所以本文孢粉组合的时代可能早于九佛堂组。

开鲁盆地与辽宁西部、内蒙古二连盆地经纬度相差不大, 处于同一气候带和植物区系 (黎文本, 1983; Li and Liu, 1994), 孢粉组合面貌有许多相似之处, 所以就横向上对比看, 本文报道的孢粉植物群与辽宁西部义县组 (张立君等, 1985; 黎文本和刘兆生, 1999)、二连盆地阿尔善组 (中国科学院南京地质古生物研究所, 1986) 孢粉组合有很大的相似性。主要表现为: (1) 三者均以裸子植物花粉占优势, 尤以双气囊松柏类花粉为多; (2) *Classopollis* 的含量很低; (3) 早期被子植物花粉零星出现或未见。不同点是: 辽西地区义县组中与海金沙科孢子有关的孢子居第二位, 见少量 *Cicatricosisporites*, 另有 *Aequitriradites*, *Couperisporites*, *Triporetetes* 等白垩纪典型分子; 二连盆地阿尔善组中早白垩世特征分子 *Cicatricosisporites*, *Klukisporites*, *Aequitriradites* 等仅个别或少量出现。当前的孢粉组合中早白垩世特征分子种类不如二连盆地和辽西地区丰富, 可能与发现孢粉化石的样品数量少有关。

5 古气候探讨

合适的温度和湿度是植物生长的必要条件,影响植物生长的最主要的因素就是气候因素,因此,植物生态与气候有着最为密切的关系。关于早白垩世最早期(义县组)沉积时期的古气候,许多学者已进行过详细的研究:黎文本和刘兆生(1999)认为辽西义县组沉积时期属于温湿气候;丁秋红和张立东(2004)认为辽西北票义县组属于湿润的亚热带—暖温带的气候环境;黎文本(2010)认为辽西义县金家沟义县组气候温暖湿润。开鲁盆地钱家店凹陷QIV-65-136井早白垩世早期孢粉植物群以裸子植物松柏类占优势,主要成分除松科(15.19%~69.7%)和原始松柏类(4.85%~38.85%)外,还有罗汉松科、掌鳞杉科、南美杉科和杉科;苏铁属仅占2.42%~9.77%;蕨类植物次之,主要成分有桫欏科(0~21.56%),紫萁科(0~9.72%)、莎草蕨科(0~12.03%)和卷柏科;未见被子植物。

从孢粉组合反映的植物群生态环境看,松科植物大都为常绿针叶乔木,稀为灌木,广布于北半球温带,其中云杉属、松属多分布于亚热带山地;原始松柏类为常绿针叶乔木,广布于北半球温带湿润的环境中;罗汉松科为常绿乔木或灌木,主要分布在南部球亚热带—热带地区;掌鳞杉科是亚热带耐干旱炎热的乔木或灌木,生长于高地斜坡(Vakhrameev, 1991;王伏雄等, 1995;江德昕和王永栋, 2002;邓胜徽, 2007);苏铁属主要产于热带和亚热带地区。桫欏科桫欏属为树蕨,多生于热带和亚热带阴湿谷和湖河沿岸的低海拔地形;莎草蕨科主要分布于南半球和赤道地区,生长在干燥贫瘠的土壤上;卷柏科分布于亚热带和温带,生长于林下或溪边湿地(中国科学院北京植物研究所古植物研究室孢粉组, 1976)。紫萁科为中型植物,少有树形,分布于热带、亚热带或温带沼泽湿地、林下溪边或阴湿的山谷(中国科学院北京植物研究所古植物研究室孢粉组, 1976)。

纵观全局,可以推测早白垩世早期的植被景观为:在湖盆周围的山地上生长着松科高大乔木,伴有罗汉松科、杉科及少量苏铁科、南美杉科、掌鳞杉科等植物,林下、湖岸地区生长着桫欏科、紫萁科及莎草蕨科等蕨类植物。古气候为湿润的暖温带—

亚热带气候。

6 结论

(1)通过对孢粉化石属种的分析,在剖面中建立了义县组 *Cyathidites-Pinuspollenites-Protoconiferus* 孢粉组合带。

(2)根据典型分子时代分布、重要种属含量上的变化及孢粉组合横向对比,表明义县组形成时代为早白垩世早期。

(3)义县组植被类型反映暖温带—亚热带气候,指示温暖湿润带的气候环境。

Reference

- Bai Jing, Xu Xingyou, Chen Shan, Liu Weibin, Liu Chang, Zhang Changsheng. 2020. Sedimentary characteristics and paleo-environment restoration of the first member of Qingshankou Formation in Qian'an area, Changling sag, Songliao Basin: A case study of Jiyeou 1 Well [J]. *Geology in China*, 47(1): 220-235 (in Chinese with English abstract).
- Beijing Institute of Botany, Chinese Academy of Sciences. 1976. *Sporae Pteridophytorum Sinicorum* [M]. Beijing: Science Press, 1-451 (in Chinese).
- Berner R A, Kothavala Z. 2001. Geocarb III: A revised model of atmospheric CO₂ over Phanerozoic time [J]. *American Journal of Science*, 301(2): 182-204.
- Bolkhovitina N A. 1961. Fossil and recent spores in the Schizaeaceae [J]. *Bulletin of Institute of Geology, Academy of Science, USSR*, 401-176.
- Chen Peiji, Chang Zhenlu. 1994. Nonmarine Cretaceous stratigraphy of eastern China [J]. *Cretaceous Research*, 15(3): 245-257.
- Chen Peiji. 2000. Comments on the classification and correlation of non-marine Jurassic and Cretaceous of China [J]. *Journal of Stratigraphy*, 24(2): 114-119 (in Chinese with English abstract).
- Chen Weijia, He Dengfa, Gui Baoling, Gao Baoli, Li Ruilei. 2014. Tectono-stratigraphic sequence and basin evolution in southern Songliao Basin [J]. *Acta Geologica Sinica*, 88(5): 932-942 (in Chinese with English abstract).
- Chengdu Institute of Geology and Mineral Resources. 1983. *Palaeontological Atlas of Southwest China, Volume of Microfossils* [M]. Beijing: Geological Publishing House, 520-654 (in Chinese).
- Crowley T J, Kim K Y. 2013. Comparison of longterm greenhouse projections with the geologic record [J]. *Geophysical Research Letters*, 22(8): 933-936.
- Cui Ying, Gong Enpu, Wang Tiehui, Guan Changqin, Zhang Yongli, Liang Junhong. 2015. Palynomorph assemblages and paleoclimate records from the Zhuanchengzi Bed of the Yixian Formation,

- western Liaoning Province, China [J]. *Science China: Earth Sciences*, 58: 1538–1552 (in Chinese).
- Deng Chenlong, He Huaiyu, Pan Yongxin, Zhu Rixiang. 2013. Chronology of the terrestrial Upper Cretaceous in the Songliao Basin, northeast Asia [J]. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 385: 44–54.
- Deng Shenghui. 2007. Palaeoclimatic implications of main fossil plants of the Mesozoic [J]. *Journal of Palaeogeography*, 9(6): 559–574 (in Chinese with English abstract).
- Ding Qihong, Zhang Lidong, Guo Shengzhe, Zhang Changjie, Peng Yandong, Jia Bin, Chen Shuwang, Xing Dehe. 2003a. Paleoclimatic and palaeoenvironmental proxies of the Yixian Formation in the Beipiao area, western Liaoning [J]. *Geological Bulletin of China*, 22(3): 186–191 (in Chinese with English abstract).
- Ding Qihong, Zhang Lidong, Guo Shengzhe, Zhang Changjie, Peng Yandong, Jia Bin, Chen Shuwang, Xing Dehe. 2003b. Study on the paleoecology of Yixian Formation in Beipiao area, western Liaoning Province, China [J]. *Journal of Precious Metallic Geology*, 12(1): 9–18 (in Chinese with English abstract).
- Ding Qihong, Zhang Lidong. 2004. Spore–pollen flora as the indicator of paleoclimate condition in the Yixian Formation, western Liaoning Province [J]. *Acta Micropalaeontologica Sinica*, 21(3): 332–341 (in Chinese with English abstract).
- Du Baoxia, Yan Defei, Sun Bainian, Deng Shenghui, Xie Sanping, Wen Wenwen. 2010. Studies on structures of several Early Cretaceous fossil conifers in Fuxin, Liaoning Province and its geological significance [J]. *Geological Journal of China Universities*, 16(3): 327–338 (in Chinese with English abstract).
- Feng Zhiqiang, Jia Chengzao, Xie Xinong, Zhang Shun, Feng Zihui, Timothy A C. 2010. Tectonostratigraphic units and stratigraphic sequences of the nonmarine Songliao basin, northeast China [J]. *Basin Research*, 22(1): 79–95.
- Gao Ruiqi, Zhao Chuanben, Qiao Xiuyun, Zheng Yulong, Yan Fengyun, Wan Chuanbiao. 1999. Palynology of the Cretaceous Oil–bearing Strata from Songliao Basin [M]. Beijing: Geological Publishing House, 1–373 (in Chinese with English abstract).
- Gradstein F M, Ogg J G, Hilgen F J. 2004. A Geologic Time Scale [J]. *Newsletters on Stratigraphy*, 45(2): 171–188.
- Haq B U, Hardenbol J, Vail P R. 1987. Chronology of fluctuating sea levels since the triassic [J]. *Science*, 235(4793): 1156.
- Herman A B, Spicer R A. 1996. Palaeobotanical evidence for a warm Cretaceous Arctic Ocean [J]. *Nature*, 380(6572): 330–333.
- Hou Lianhai, Zhou Zhonghe, Martin L D, Feduccia A. 1995. A beaked bird from the Jurassic of China [J]. *Nature*, 377(6550): 616–618.
- Ji Qiang, Ji Shu'an. 1996. The discovery of the oldest fossil birds and the origin of birds [J]. *Geology in China*, (10): 30–33 (in Chinese).
- Ji Qiang, Ji Shu'an. 1997. Archaeopteryx (Protarchaeopteryx gen.nov.): Archaeopteryx–typefossils of China [J]. *Geology in China*, (3): 38–41 (in Chinese).
- Jiang Dexin, Wang Yongdong. 2002. Middle Jurassic palynoflora and its environmental significance of Dongshe, Inner Mongolia [J]. *Acta Sedimentologica Sinica*, 20 (1): 47–54 (in Chinese with English abstract).
- Keller G. 2008. Cretaceous climate, volcanism, impacts, and biotic effects [J]. *Cretaceous Research*, 29(5/6): 754–771.
- Krutzsch W. 1959. Einige neue Formgattungen und –arten von Sporen und Pollen aus der mitteleuropaischen Oberkreide und dem Tertiär [J]. *Palaeontographica*, 105: 125–157.
- Li Fengxia. 2005. A sporopollen assemblage from the early Cretaceous Fuxin Formation in the Kailu Basin [J]. *Acta Micropalaeontologica Sinica*, 22(1): 87–96 (in Chinese with English abstract).
- Li J, Batten D J. 2007. Palynological evidence of an Early Cretaceous age for the Yixian Formation at Sihetun, western Liaoning, China [J]. *Cretaceous Research*, 28(2): 333–338.
- Li Peixian, Su Deying, Li Yougui, Huang Jiafu, Cheng Shoutian, Xia Wenchen, Zhao Genrong. 1993. The chronostratigraphic status of the Lycopoda–bearing bed [J]. *Acta Geologica Sinica*, 68(1): 87–100 (in Chinese with English abstract).
- Li Wenben, Liu Zhaosheng. 1994. The Cretaceous palynofloras and their bearing on stratigraphic correlation in China [J]. *Cretaceous Research*, 15(3): 333–365.
- Li Wenben, Liu Zhaosheng. 1999. Sporomorph assemblage from the basal Yixian Formation in western Liaoning and its geological age [J]. *Palaeoworld*, 11: 68–79 (in Chinese with English summary).
- Li Wenben. 1983. Early Cretaceous sporo–pollen flora and their geographic zoning in China [C]//Lu Yanhao (ed.). *Paleontologic Geographic Flora*. Beijing: Geological Publishing House, 142–151 (in Chinese with English abstract).
- Li Wenben. 2010. Palynological assemblage from the Zhuanchengzi beds of Yixian Formation in Jinjiagou, Yixian [J]. *Acta Palaeontologica Sinica*, 49(1): 44–53 (in Chinese with English abstract).
- Luo Yi, He Zhongbo, Ma Hanfeng, Sun Xiang. 2012. Metallogenic characteristics of Qianjiadian sandstone uranium deposit in Songliao Basin [J]. *Mineral Deposits*, 31(2): 391–400 (in Chinese with English abstract).
- Miller K G, Kominz M A, Browning J V, Wright J D, Mountain G S, Katz M E, Sugarman P J, Cramer B S, Christie–Blick N, Pekar S F. 2005. The Phanerozoic record of global sea–level change [J]. *Science (New York, N.Y.)*, 310(5752): 1293–1298.
- Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences. 1986. Cretaceous Ostracoda and Sporopollen in the Erlian Basin, Inner Mongolia [M]. Hefei: Anhui Science and Technology Publishing House, 168–278 (in Chinese).
- Norris G. 1977. Discrimination and correlation of highest Jurassic and lowest cretaceous terrestrial palynofloras in north–west Europe [J]. *Palynology*, 1(1): 79–93.
- Rong Hui, Jiao Yangquan, Wu Liqun, Ji Dongmin, Li Hongliang, Zhu Qiang, Cao Minqiang, Wang Xiaomei, Li Qingchun, Xie Huili. 2016. Epigenetic alteration and its constraints on uranium mineralization from the Qianjiadian uranium deposit, southern Songliao Basin [J]. *Earth Science*, 41(1): 153–166 (in Chinese with English abstract).
- Shang Fei, Zhou Haiyan, Liu Yong, Zhou Xuexian, Wang Lan, Bi He,

- Wang Guochang, Song Li, Chen Ruiqian. 2020. A discussion on the organic matter enrichment model of the Nenjiang Formation, Songliao Basin: A case study of oil shale in the 1st and 2nd members of the Nenjiang Formation [J]. *Geology in China*, 47(1): 236–248 (in Chinese with English abstract).
- Shang Yuke. 1991. Discovery of early Cretaceous pollen and spores from the Luozigou Basin, Wangqing country, Jilin [J]. *Acta Micropalaeontologica Sinica*, 8(4): 405–422 (in Chinese with English abstract).
- Stoll H M, Schrag D P. 1996. Evidence for glacial control of rapid sea level changes in the Early Cretaceous [J]. *Science*, 272(5269): 1771.
- Stratigraphical Group of Institute of Geology, CAGS. 1989. The Paleontology and Stratigraphy of the Jurassic and Cretaceous in eastern China [M]. Beijing: Geological Publishing House, 1–170 (in Chinese with English abstract).
- Sun Xiao, Deng Shaoying, Wu Yang, Liu Hongzhang, Shen Jinqing. 2017. Redefinition of the Shanwanzi Mesozoic stratigraphic sequence in the north Hebei Province [J]. *Geological Survey and Research*, 40(1): 1–12 (in Chinese with English abstract).
- Sun Ge, Zheng Shaolin. 2000. New proposal on division and correlation of Mesozoic from Northeastern China [J]. *Journal of Stratigraphy*, 24(1): 60–64 (in Chinese with English abstract).
- Tang Qingsi, Yang Junquan, Tian Chao, Jin Ruoshi, Li Jianguo, Ao Cong, Zhang Zegui. 2016. In-situ leaching for sandstone type uranium deposit in Songliao basin and ecological conservation [J]. *Geological Survey and Research*, 39(2): 136–139 (in Chinese with English abstract).
- Tianjin Institute of Geology and Mineral Resources. 1984. Palaeontological Atlas of North China, Paleozoic Volume [M]. Beijing: Geological Publishing House, 1–639 (in Chinese).
- Vakhrameev V A. 1991. Jurassic and Cretaceous Floras and Climates of the Earth [M]. Cambridge: Cambridge University Press, 1–318.
- Wang Daning, Wang Xuri, Ji Qiang. 2016. The palynoflora alternation and the paleoclimate change at the turning time between Late Jurassic and Early Cretaceous in Northern Hebei and Western Liaoning [J]. *Acta Geoscientia Sinica*, 37(4): 449–459 (in Chinese with English abstract).
- Wang Fuxiong, Qian Nanfen, Zhang Yulong, Yang Huiqiu. 1995. Pollen Flora of China (second edition) [M]. Beijing: Science Press, 1–461 (in Chinese).
- Wang Renhou, Xu Kun, Qin Derong, Li Yu, Li Ronghui, Wu Bingwei. 1999. Mesozoic Fauna and Stratigraphy in the Adjacent Area of Liaohu [M]. Beijing: Petroleum Industry Press, 1–216 (in Chinese).
- Wang Sien, Cheng Zhenwu, Wang Naiwen, Zhang Zhicheng, Xu Fuxiang, Zhang Renjie, Yan Yongkui. 1982. Jurassic System of China [M]. Beijing: Geological Publishing House, 1–350 (in Chinese with English abstract).
- Wang Sien. 1998. Correlation of the Continental Jurassic in the north of China to the Paralic Jurassic in Northwest Scotland, United Kingdom—With a Discussion of the Stratigraphic Subdivision and Correlation of the Jurassic in the North of China [J]. *Acta Geologica Sinica*, 72(1): 11–21 (in Chinese with English abstract).
- Wang Sien. 1999. Palaeoecology and palaeoenvironment of the Jehol Biota—A palaeoecology and palaeoenvironmental reconstruction of conchostracan palaeocommunities in the northern Hebei–Western Liaoning Area [J]. *Acta Geologica Sinica*, 73(4): 289–301 (in Chinese with English abstract).
- Wang Wuli, Zhang Hong, Zhang Lijun, Zheng Shaolin, Yang Fanglin, Li Zhitong, Zheng Yuejuan. 2003. Stratigraphic sequence of the Yixian Formation of Yixian Beipiao region, Liaoning—A study and establishment of stratotype of the Yixian stage [J]. *Journal of Stratigraphy*, 27(3): 227–232 (in Chinese with English abstract).
- Wang Xiaolin, Wang Yuanqing, Wang Yuan, Xu Xing, Tang Zhilu, Zhang, Fucheng, Hu Yaoming. 1998. Stratigraphic sequence and vertebra-bearing beds of the lower part of the Yixian Formation in Sihetun and neighboring area, western Liaoning, China [J]. *Vertebrata Palasiatica*, 36(2): 81–101 (in Chinese with English abstract).
- Wu Bingwei. 2006. Early Cretaceous spores and pollen assemblages of Kailu Basin, Nei Mongol [J]. *Acta Palaeontologica Sinica*, 45(4): 549–562 (in Chinese).
- Wu Bingwei. 2007. Discovery of the three biotas in the Cretaceous of Kailu Basin, Nei Mongol and their geological significance [J]. *Journal of Stratigraphy*, 31(3): 280–287 (in Chinese).
- Xu Kun, Li Yu. 1995. Late Mesozoic strata of the Kailu Basin [J]. *Journal of Stratigraphy*, 19(2): 88–95 (in Chinese with English abstract).
- Xu Zenglian, Tang Chao, Wei Jialin, Zeng Hui, Xiao Peng, Liu Huajian. 2021. Late Cretaceous palynological record and its paleoclimate significance in the southern of Daqing placanticline [J]. *North China Geology*, 44(2): 74–80 (in Chinese with English abstract).
- Yan Yi, Lin Ge, Li Zian. 2003. Mesozoic environment change and biocoenose evolution in western Liaoning Province [J]. *Geological Science and Technology Information*, 22(1): 56–60 (in Chinese with English abstract).
- Yu Jingxian. 1986. The sporo-pollen assemblage from the Zuoyun Formation in northwestern Shangxi and paleoclimate [J]. *Geological Review*, 32(3): 217–224 (in Chinese with English abstract).
- Zhang Dejun, Zhang Jian, Su Fei, Zheng Yuejuan, Chen Shuwang, Zhang Haihua, Huang Xin, Zhang Yujin. 2019. Late Cretaceous conchostracan fossils discovered in Nenjiang formation, southwest uplift of Songliao Basin [J]. *Geology and Resources*, 28(3): 6, 231–235 (in Chinese with English abstract).
- Zhang Lijun, Pu Ronggan, Wu Hongzhang. 1985. The Mesozoic Paleontology in Western Liaoning [M]. Beijing: Geological Publishing House, 123–130 (in Chinese).
- Zhao Chuanben. 1987. Early Cretaceous Sporopollen Assemblage in Erlian Basin [M]. Beijing: The Petroleum Industry Press, 1–62 (in Chinese).

附中文参考文献

白静, 徐兴友, 陈珊, 刘卫彬, 刘畅, 张昌盛. 2020. 松辽盆地长岭凹陷

- 乾安地区青山口组一段沉积相特征与古环境恢复——以吉页油1井为例[J]. 中国地质, 47(1): 220-235.
- 陈丕基. 2000. 中国陆相侏罗、白垩系划分对比述评[J]. 地层学杂志, 24(2): 114-119.
- 陈为佳, 何登发, 桂宝玲, 高丽明, 李瑞磊. 2014. 松南地区构造-地层层序与盆地演化[J]. 地质学报, 88(5): 932-942.
- 崔莹, 巩恩普, 王铁晖, 关长庆, 张永利, 梁俊红. 2015. 辽西义县组砖城子层孢粉组合时代及古气候记录[J]. 中国科学:地球科学, 45(8): 1138-1152.
- 邓胜徽. 2007. 中生代主要植物化石的古气候指示意义[J]. 古地理学报, 9(6): 559-574.
- 地质矿产部成都地质矿产研究所. 1983. 西南地区古生物图册, 微体古生物分册[M]. 北京: 地质出版社, 520-654.
- 丁秋红, 张立东, 郭胜哲, 张长捷, 彭艳东, 贾斌, 陈树旺, 邢得和. 2003a. 辽西北票地区义县组古气候环境标志及其意义[J]. 地质通报, 22(3): 186-191.
- 丁秋红, 张立东, 郭胜哲, 张长捷, 彭艳东, 贾斌, 陈树旺, 邢得和. 2003b. 辽西地区义县组植物群古生态研究[J]. 地质与资源, 12(1): 9-18.
- 丁秋红, 张立东. 2004. 辽西义县组孢粉植物群指示的古气候条件[J]. 微体古生物学报, 21(3): 332-341.
- 杜宝霞, 闫德飞, 孙柏年, 邓胜徽, 解三平, 温雯雯. 2010. 辽宁阜新早白垩世几种松柏类化石微细构造及地质意义[J]. 高校地质学报, 16(3): 327-338.
- 高瑞祺, 赵传本, 乔秀云, 郑玉龙, 闫凤云, 万传彪. 1999. 松辽盆地白垩纪石油地层孢粉学[M]. 北京: 地质出版社, 1-373.
- 季强, 姬书安. 1996. 中国最早鸟类化石的发现及鸟类的起源[J]. 中国地质, 10: 30-33.
- 季强, 姬书安. 1997. 原始祖鸟——中国的始祖鸟类化石[J]. 中国地质, 3: 38-42.
- 江德昕, 王永栋. 2002. 内蒙古东胜中侏罗世孢粉植物群与沉积环境[J]. 沉积学报, 20(1): 47-54.
- 黎文本. 1983. 中国早白垩世孢粉植物群及其地理分区[C]//卢衍豪. 中国古生物地理区系. 北京: 地质出版社, 142-151.
- 黎文本. 2010. 辽宁义县金家沟义县组砖城子层孢粉组合[J]. 古生物学报, 49(1): 44-53.
- 李凤霞. 2005. 内蒙古开鲁盆地早白垩世阜新组孢粉组合[J]. 微体古生物学报, 22(1): 87-96.
- 李佩贤, 苏德英, 李友桂, 黄家福, 成守田, 夏文臣, 赵根榕. 1993. 狼鳍鱼(Lycoperia)岩层的时代归属[J]. 地质学报, 68(1): 87-100.
- 罗毅, 何中波, 马汉峰, 孙祥. 2012. 松辽盆地钱家店砂岩型铀矿成矿地质特征[J]. 矿床地质, 31(2): 391-400.
- 荣辉, 焦养泉, 吴立群, 季东民, 里宏亮, 朱强, 曹民强, 汪小妹, 李青春, 谢惠丽. 2016. 松辽盆地南部钱家店铀矿床后生蚀变作用及其对铀成矿的约束[J]. 地球科学, 41(01): 153-166.
- 商斐, 周海燕, 刘勇, 周学先, 王岚, 毕赫, 王国昌, 宋力, 陈睿倩. 2020. 松辽盆地嫩江组泥页岩有机质富集模式探讨——以嫩江组一、二段油页岩为例[J]. 中国地质, 47(1): 236-248.
- 尚玉珂. 1991. 吉林汪清罗子沟盆地早白垩世孢粉化石之发现[J]. 微体古生物学报, 8(4): 405-422.
- 孙肖, 邓绍颖, 吴洋, 刘洪章, 申晋青. 2017. 冀北围场山湾子中生代地层层序的重新厘定[J]. 地质调查与研究, 40(1): 1-12.
- 孙革, 郑少林. 2000. 中国东北中生代地层划分对比之新见[J]. 地层学杂志, 24(01): 60-64.
- 汤庆四, 杨俊泉, 田超, 金若时, 李建国, 奥琮, 张泽贵. 2016. 松辽盆地砂岩型铀矿地浸采冶与生态保护——以钱家店铀矿为例[J]. 地质调查与研究, 39(2): 136-139.
- 天津地质矿产研究所. 1984. 华北地区古生物图册, 古生代分册[M]. 北京: 地质出版社, 1-639.
- 汪筱林, 王元青, 王原, 徐星, 唐治路, 张福成, 胡耀明, 顾罡, 郝兆林. 1998. 辽西四合屯及周边地区义县组下部地层层序与脊椎动物化石层位[J]. 古脊椎动物学报, 36(2): 81-101.
- 王大宁, 王旭日, 季强. 2016. 冀北—辽西地区侏罗—白垩纪之交期的孢粉植物群演替与古气候变化[J]. 地球学报, 37(4): 449-459.
- 王伏雄, 钱南芬, 张玉龙, 杨惠秋. 1995. 中国植物花粉形态(第二版)[M]. 北京: 科学出版社, 1-461.
- 王仁厚, 许坤, 秦德荣, 李瑜, 李荣辉, 吴炳伟. 1999. 辽河油田外围探区中生代生物地层[M]. 北京: 石油工业出版社, 1-216.
- 王思恩, 程振武, 王乃文, 张志诚, 徐福祥, 孙东立, 张仁杰, 阎永奎. 1982. 中国侏罗系[M]. 北京: 地质出版社, 1-350.
- 王思恩. 1998. 中国北部陆相侏罗系与英国海陆交互相侏罗系的对比研究——兼论中国北部侏罗系的划分与对比[J]. 地质学报, 72(1): 11-21.
- 王思恩. 1999. 热河生物群的古生态与古环境——冀北、辽西叶肢介群落古生态与古环境重建[J]. 地质学报, 73(4): 289-301.
- 王五力, 张宏, 张立君, 郑少林, 杨芳林, 李之彤, 郑月娟. 2003. 辽宁义县—北票地区义县组地层层序——义县阶标准地层剖面建立和研究之一[J]. 地层学杂志, 27(3): 227-232.
- 吴炳伟. 2006. 内蒙古开鲁盆地早白垩世孢粉组合[J]. 古生物学报, 45(4): 549-562.
- 吴炳伟. 2007. 内蒙古开鲁盆地白垩纪三大生物群的发现及其地质意义[J]. 地层学杂志, 31(3): 280-287.
- 许坤, 李瑜. 1995. 开鲁盆地晚中生代地层[J]. 地层学杂志, 19(2): 88-95.
- 徐增连, 汤超, 魏佳林, 曾辉, 肖鹏, 刘华健. 2021. 大庆长垣南端晚白垩世孢粉组合特征及其古气候记录[J]. 华北地质, 44(2): 74-80.
- 闫义, 林舸, 李自安. 2003. 辽西地区中生代环境变迁及生物演替[J]. 地质科技情报, 22(1): 56-60.
- 余静贤. 1986. 晋西北左云组孢粉组合及古气候探讨[J]. 地质论评, 32(3): 217-224.
- 张德军, 张健, 苏飞, 郑月娟, 陈树旺, 张海华, 黄欣, 张渝金. 2019. 松辽盆地西南隆起区发现晚白垩世嫩江组叶肢介化石[J]. 地质与资源, 28(3): 231-235.
- 张立君, 蒲荣干, 吴洪章. 1985. 辽宁西部中生代地层古生物[M]. 北京: 地质出版社, 123-130.
- 赵传本. 1987. 二连盆地早白垩世孢粉组合[M]. 北京: 石油工业出版社, 1-62.
- 中国地质科学院地质研究所地层组. 1989. 中国东部侏罗纪—白垩纪古生物及地层[M]. 北京: 地质出版社, 1-170.
- 中国科学院北京植物研究所古植物研究室孢粉组. 1976. 中国蕨类植物孢子形态[M]. 北京: 科学出版社, 1-451.
- 中国科学院南京地质古生物研究所. 1986. 内蒙古二连盆地白垩纪介形类和孢粉化石[M]. 合肥: 安徽科学技术出版社, 168-278.