

第四纪地层中壳斗科植物花粉化石及其与气候地理条件的关系*

唐领余¹⁾ 李春海²⁾** 张小平³⁾** 邵剑文³⁾ 周忠泽⁴⁾ 凌超豪²⁾

1) 中国科学院南京地质古生物研究所, 南京 210008;

2) 中国科学院南京地理与湖泊研究所, 南京 210008, chhli@niglas.ac.cn;

3) 安徽师范大学生命科学学院, 安徽芜湖 241000, pinghengxu@sina.com;

4) 安徽大学资源与环境工程学院, 合肥 230000

提要 壳斗科植物花粉化石是被子植物花粉化石最为丰富的类群之一, 在地史上自第三纪以来一直是中国各地质历史时期中植物区系的一个主要成分。据初步统计, 我国第四纪地层中共发现壳斗科花粉化石有 6 属: *Castanea*, *Castanopsis*, *Lithocarpus*, *Cyclobalanopsis*, *Fagus* 及 *Quercus*, 后者还分出含常绿栎类 *Quercus*(E) 和落叶栎类 *Quercus*(D) 两种类型。文中对 6 属中花粉形态相似的 *Castanea*, *Castanopsis* 和 *Lithocarpus* 3 属, 以及 *Cyclobalanopsis* 和 *Quercus*(E) 花粉, 从花粉粒形状和大小、萌发孔数量和形状、极面×赤道面的平均大小、最长极轴与最长赤道轴比以及外壁表面纹饰等多方面进行详细数值对比和照片对照, 提出鉴定要点, 希望能提高壳斗科花粉化石鉴定的准确性。同时, 文中还讨论中国壳斗科各属植物生长的气候地理条件和生态环境。*Castanopsis* 和 *Lithocarpus* 花粉化石分布中心范围在北纬 28°—20°, 反映该两属生长气候要求大约是年平均气温不低于 15 °C, 年降水量不少于 1 000 mm; *Cyclobalanopsis* 和 *Fagus* 花粉化石的产地在秦岭—淮河一线以南, 生长的地理气候条件要求是 1 月份气温不低于 0 °C, 年均温在 8—15 °C 以上, 年降水量不少于 800 mm 的温暖湿润的生态环境; *Castanea* 和 *Quercus* 花粉化石在全国各地均有发现, 分布北界达北纬 36°—50°, 反映该两属生长的生态幅度较 *Castanopsis*/*Lithocarpus* 宽得多, 基本的生长气候范围在年均温 3.5—23 °C, 能够忍受 1 月份低于 10 °C 的寒冷, 也能够经受 7 月份近 30 °C 的高温考验, 年均降水量约为 500—1 700 mm。希望该研究能为提高再造第四纪古植被和古环境, 提供一些有说服力的气候地理条件的原始资料。

关键词 壳斗科 花粉化石 花粉形态 气候地理条件 第四纪地层

壳斗科(Fagaceae)植物是被子植物中古老类群之一, 是北半球热带、亚热带和温带最重要的森林树种, 全球有 9 属, 近 1 000 种, 间断分布于欧亚大陆和美洲大陆。依据《中国植物志》(中国科学院中国植物志编辑委员会, 1998) 确认中国有栗属(*Castanea*)、锥属(*Castanopsis*)、水青冈属(*Fagus*)、柯属(*Lithocarpus*)、栎属(*Quercus*)、青冈属(*Cyclobalanopsis*) 和三棱栎属(*Trigonobalanus*) 等 7 属, 约 300 种。除新疆有引种外, 自然分布于南北各省区, 主要产于西南及南部。自沿海低丘陵至海拔约 3 900 m 高山均有生长, 常为山地常绿阔叶或针叶阔叶混交林的主要上层树种, 又是山地水源林的重

要成分, 也是秦岭南坡以南各地的主要用材树种。根据现有资料, 壳斗科植物花粉化石是被子植物花粉化石最为丰富的类群之一, 在地史上自第三纪以来一直是中国各地质历史时期中植物区系的一个主要成分。据不完全统计, 在中国第四纪地层中除 *Trigonobalanus* 外, 其他 6 属均有发现, 并在各地第四纪孢粉组合中占很大比例, 对恢复第四纪古植被与古气候起着重要的作用。然而在第四纪孢粉研究中对壳斗科里 *Castanea*, *Castanopsis*, *Lithocarpus* 和 *Cyclobalanopsis* 及 *Quercus* 里常绿类 *Quercus*(E) 和落叶类 *Quercus*(D) 的形态鉴别仍存在难以区别的问题。本文针对上述问题对以上各

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** 通讯作者: 李春海, 副研究员, 主要从事第四纪环境考古研究; 张小平, 教授, 主要从事植物学研究。

属的现代花粉和化石花粉形态进行了详细对比,提出鉴定要点,希望能提高壳斗科花粉化石鉴定的准确性。

壳斗科植物花粉不仅形态多样,而且有些属花粉形态有很大相似性。这样的丰富度和特有性是壳斗科祖先在长期地质地理和气候环境演变中形成的。也就是说与壳斗科各属植物生长的气候地理条件密切相关。而第四纪孢粉学研究者往往对这一点研究尚不足或理解不深,在很大程度上影响了以花粉记录重建古气候的可靠性。为此,本文还讨论了中国壳斗科各属植物生长的气候地理条件和生态环境,希望本研究能为提高第四纪孢粉研究水平补充一些参考资料。

1 壳斗科植物花粉化石在我国的发现

1.1 中国壳斗科植物花粉化石在晚白垩世—新近纪地层中的发现

地史上壳斗科花粉化石最早出现于晚白垩世早期的欧亚、北美及大洋洲和南美洲地层中,化石花粉中主要是以表面细或较粗颗粒的三沟或三拟孔沟的壳斗粉属(*Cupuliferoidacpollenites*)、栗粉属(*Cupuliferoiipollenites*)和栎粉属(*Quercoidites*)三属为主。在中国该科最早花粉化石是发现于黑龙江大庆晚白垩世早期—中期的壳斗粉[*Cupuliferoidacpollenites parvalus* (Groot and Penny) Dotternam](高瑞祺,1999)、发现于云南勐腊晚白垩世的小亨氏栎粉[*Quercoidites microhenrii* (Potonie), Potonie](宋之琛、李曼英,1976)以及发现于黑龙江肇东晚白垩世早期的坚实栎粉(*Quercoidites solidus* Song, Li and Zheng, 1986)。此后,在我国晚白垩世晚期至新近纪各地地层中相继发现栎粉属(*Quercoidites* Potonie Thomson and Thiesgart, 1950)、栗粉属(*Cupuliferoiipollenites* Potonie, 1951 或 Potonie, 1960)及山毛榉粉属(*Faguspollenites* Rauts, 1937)三个属的很多种类花粉化石,如在东海陆架及苏北盆地海龙井组和灵峰组上段发现的粒纹栎粉[*Quercoidites granopollenites* (Rouse) M. R. Sun, 1989]、球形栎粉(*Q. orbicularis* Wang, 1985)及圆形栎粉[*Q. rotundus* (Zakil) Ke and Shi, 1978];发现于南海陆架盆地珠江组和韩江组的小孔栗粉(*Cupuliferoiipollenites minitriniatus* Song sp. nov.)和卵形栗粉[*C. oviiformis* (Pot.) Pot-

onie, 1951],以及分布于全国各地第三系的带型栗粉[*C. cingulum* (Pot.) Song and Zheng, 1981]和梭形栗粉[*C. fusus* (Pot.) Potonie, 1960]。还有发现于湖北江汉平原潜江组的假叉形山毛榉粉[*Faguspollenites pseudocruciatum* (Pot.) Potonie, 1960]和皱壁山毛榉粉[*F. ragosus* (Wang and Zhao) Song Comb. nov.];以及发现于渤海盆地馆陶组至明化镇组的近圆形山毛榉粉[*F. subrotundus* (Zheng) Song Comb. nov.]和真山毛榉粉(*F. verus* Roats, 1937)。这些花粉化石的植物亲缘关系都属壳斗科植物的栎属(*Quercus*)、栗属(*Castanea*)和山毛榉属(*Fagus*),其花粉形态也与这些属的现代植物花粉形态相似(宋之琛等,1999)。

1.2 中国第四纪地层中壳斗科花粉化石的分布

根据不完全统计,中国各省、自治区及台湾地区的第四纪地层中均发现有壳斗科花粉化石,从南海南部低纬度(4.7°N)到黑龙江北部(50°N)发现的壳斗科花粉化石主要有 *Quercus*, *Fagus*, *Castanea*, *Castanopsis*, *Lithocarpus*, *Cyclobalanopsis* 以及 *Quercus* (E),其中 *Quercus* 和 *Castanea* 全国南北均有产出,且频繁出现,*Fagus* 最北出现于秦岭淮河以南地区,主要产于湖北神农架和台北盆地;*Castanopsis*, *Lithocarpus* 以及 *Cyclobalanopsis* 主要产于长江以南热带—亚热带地区(表 I)。

从表 I 中可以看出,由于 *Castanea*, *Castanopsis* 和 *Lithocarpus* 花粉形态均为三孔沟、光滑或细颗粒纹饰而难以区分。孢粉研究者对这几个属的鉴定尚存在一些问题:问题 1,有的研究者将 *Castanopsis* 和 *Lithocarpus* 或 *Castanopsis* 和 *Castanea* 合并一起统计,作为一个属对待,前者还“有情可原”,它们的形态、大小非常相似,且都是属于常绿类型的植物花粉,后者将一个常绿类和一个落叶类的两个属花粉合并处理是“不能原谅”的;问题 2,有较多研究者尚不认为 *Cyclobalanopsis* 是独立属,孢粉鉴定中没有定出该属,或者把这类花粉归到 *Quercus*,甚至将其归到其它科属;问题 3, *Quercus* (E) 没有统一的鉴定标准,或者鉴定到其它属或科。这些问题可能使同一个地区的第四纪孢粉组合出现统计上的明显误差,以至于导致孢粉谱解释上的明显差异。所以应加强壳斗科花粉各属种的花粉形态的深入研究。

表 I 中国第四纪地层中发现的壳斗科花粉化石
Producing area of Fagaceae fossil Pollen in Quaternary deposits of China.

地点	年代 (ka BP)	落叶类型(%)			常绿类型(%)			来源
		<i>Fagus</i>	Q. (D)	<i>Cas.</i>	Q. (E)	<i>Cyc.</i>	<i>Cast./Li.</i>	
南海南部	26—0.95		1—20			0—5		Sun <i>et al.</i> , 1999, 2000; 孙湘君等, 2001
南沙海区	表层		0.6—0.8			0.5—5.4	0.6—7.6	唐领余等, 1989
南沙海区(87-8柱)	晚更新世					2—8	5—10	
南海北部	表层		0—5		5—30		0—10	Dai <i>et al.</i> , 2014
南海北部	18.8—1.6		5—20				0—5	Dai and Weng, 2015
海南岛双池	7.2—0				0—10			郑卓等, 2003
广东潮汕平原	50—现今	10.4	0.5		23.4		10—55	郑卓, 1991
广东珠江三角洲	40—现今	0—6			0—26			陈木宏等, 1994
广东珠江三角洲	更新世—全新世		3			2—7	5—35	沈才明等, 1989
广东深圳前海	晚更新世	<1	>5					吴作基、余金凤, 1987
广东番禺	2.4—0		0—10			5—15		李平日等, 1991
广东韩江沉海	全新世		4.4		25.9		40	郑卓, 1990
雷州半岛田洋	400—15.8		10—47		15—56		10—40	Zheng and Lei, 1999
广东黄茅海	晚更新世	5—30			0—8			雷作淇、郑卓, 1990
广西钦州湾	全新世		2—10				0—6	李贞等, 2010
广西桂林	5.4—0.4		0.5	0.5	2.6—38		0—5	周建超等, 2015
香港元朗山	晚更新世	<2	>10			<10	2—10	唐领余、黎权伟, 1998
香港大亚湾	表层			10—40				陈炽新等, 2004
香港西贡壕涌	4.2—3.2					5—25	5—30	杨士雄等, 2011
云南星云湖	9—0.05	0—5	2.1—10.7		6.5—33.5			Chen Fa-hu <i>et al.</i> , 2014
云南星云湖	36.4—13.4		2.3—6.24		5—25			Chen Xue-mei <i>et al.</i> , 2014
云南天才湖	13.0—0.4		0—13		20		3	肖霞云等, 2007; Xiao <i>et al.</i> , 2014
云南鹤庆盆地	278—11.4		0—10	0—10		0—5		
云南泸沽湖	15.0—0		5—15			5—30	0—10	郑茜等, 2014
云南勐遮盆地	32.3—0		5—15	10—40				刘金陵、唐领余, 1987
云南松桦盆地	早更新世		10—20		20			李文漪、吴细芳, 1978
云南滇池草海	表层					6.8—12.5	1—5.5	孙湘君、吴玉书, 1987
云南滇池	晚更新世		5—25				0—15	
云南绿丰	10—0		2—13.1			0.5—9		孙湘君、吴玉书, 1980
云南洱海盆地	8.8—0				20—40		0—15	沈吉等, 2004
云南昆明盆地	中更新世	0—15	0—10	5—35		10	5—20	唐领余, 1989
云南洱海盆地	中更新世	0—5	0—10	0—5			5—30	
云南西盟	全新世		1.3—3.3	0.4—1.1	2.2—10	0.5—2	6.5—15.8	本文
云南高黎贡山	表土				1.2—3.5	0—15.2	5.9—60	
贵州大干坝	晚更新世	5—20	5—15			2—20		韩辉友、俞锦标, 1988
贵州梵净山九龙池	11—2.7		2.1—23.4			14.1—59		乔玉楼等, 1996
广西钦州湾海岸	0.15—0	<5	<1	<5	0—5		2—10	李贞等, 2010
广西桂林熔岩区	5.4—0.38		<1		5—38	0—5		周建超等, 2015

续表 I

Table I (continued)

地点	年代 (ka BP)	落叶类型(%)			常绿类型(%)			来源
		<i>Fagus</i>	Q. (D)	<i>Cas.</i>	Q. (E)	<i>Cyc.</i>	<i>Cast. /Li.</i>	
四川冕宁	10.7—0		5—38		10—43			Jarvis <i>et al.</i> , 1993
四川义敦	9.5—0		5—25					Shen <i>et al.</i> , 2006
四川若尔盖	190—7		0—15					Shen Cai-ming <i>et al.</i> , 2005
四川螺髻山	表土		23.7		3.4	34.9		李旭、刘金陵, 1988
四川螺髻山	12.4—2		5—25		10—30	0—5		
重庆玉溪	6.2—0	3.8—5.9	5.1		8.6			崔安宁等, 2015
西藏东南	中全新世		2.8					Shen <i>et al.</i> , 2008
西藏东南-西北	表土		0—75					Shen <i>et al.</i> , 2006
西藏西南湖泊	表层		0—3.2					Ma <i>et al.</i> , 2014
西藏塔拉错	13.5—1.9		0—2.3					Ma <i>et al.</i> , 2017
西藏错鄂	250		0.5		0.2			吕厚远等, 2001
西藏纳木错	120—4.22		0.5—4	<1				吴中海等, 2004
西藏当雄	9.1—7.1		0.1					汪佩芳等, 1981
西藏海登湖	12—0		2—6					唐领余等, 2004
唐古拉山垭口	4.2—0.038		0—5					唐领余等, 2009
西藏色林错	12.2—0.7		0—25					孙湘君等, 1993
福建屏南	50—2	0—10	15—60		5—20			Yue <i>et al.</i> , 2012
福建戴云山	4.35—0.55	0—0.4	0—1.4		1.2—27			Zhao <i>et al.</i> , 2016
福建龙海	8—0		3.4—5.5		10.6—17			李永飞, 2014
福建东山	24.7—0		2.2—		8.0—20.8			
福建霞浦	6.7—0		3.2—4.8		5.6—21.7			
台湾台北盆地	中更新世	3—38	13—50				2—20	Liew, 1977
台湾东源湖	1.5—0		0—15				5—30	Lee and Liew, 2010
台湾 Toushe 湖	25—0		1—1.5			1—30	1—15	Liew <i>et al.</i> , 2006a
台湾 Toushe 盆地	80.5—1.8			5—30	10—40	10—35	5—80	Liew <i>et al.</i> , 2006b
台湾 Jih Tan	60—0.03		5—55				2—25	Tsukada, 1967
浙江宁波平原	晚更新世		5—45	2—30		5—25	0—5	王开发、张玉兰, 1985
浙江萧山	8.2—7.6		5—70			0—10		Shu <i>et al.</i> , 2010
江西南昌东坞	3.6—0	0—8	2—8				0—2	韩辉友, 1985
江西西山	1.3—0		30			4.6		崔安宁等, 2015
上海松泽	5.4—2.5		5—15			0—20	0—20	王开发等, 1980
上海面粉厂	9.5—0.5		5—20	5—30		5—15		
上海金山	3.85		5—20	0—5				
上海	晚更新世	<5	<5	5—33				刘金陵、叶萍宜, 1977
上海广富林遗址	5.3—0		0—8.6			1.1	3.7	李春海等, 2006
江苏太湖	6.5—2.5		10—25			5—10	0—5	舒军武, 2007
江苏太湖	11—0		10—30	<5		5—10	1—5	许雪珉、刘金陵, 1996
江苏溧阳	7—2.5	0—10	0.6—10.2			9.2—19.6		马春梅、田名利, 2010
江苏句容	6.7—5.6		53.9			8	4.4	韩辉友等, 2000

续表 I

Table I (continued)

地点	年代 (ka BP)	落叶类型(%)			常绿类型(%)			来源
		<i>Fagus</i>	Q. (D)	<i>Cas.</i>	Q. (E)	<i>Cyc.</i>	<i>Cast. /Li.</i>	
江苏青墩	11.9—0		20—35			5—20		刘鸿雁等,1994
江苏江阴	10—0		5—10		215			徐馨、朱明伦,1984
江苏镇江	9.7—4.0		13.2—68.4					
江苏扬州	4.5—0		5—48	5—45		0—25		萧家仪等,1995
江苏建湖	10—1.27		9.2—26	0.5—6.6		0.9—8.6	0.8—4	唐领余等,1993
南京紫金山	表土		56.1			0.3	0.2	于革、韩辉友,1995
南京仙林	森林上空		5.6—21.2					Fang <i>et al.</i> , 2015
南京仙林	草地上空		0.6—3.1					
江苏连云港	3.9—3.3		1—34	0—10	0—10			赵琳等,2014
安徽巢湖	9.8—1.0		5—45			5—20	0—20	吴立等,2008
安徽巢湖	10.5—1.0	0.5	2.2—22.2			4.9—37.2	0—5	Chen <i>et al.</i> , 2009
安徽蚌埠	4.5—4		5—20					赵琳等,2013
湖北大神龙架	2.0—0		30—50					李文漪,1991
湖北大九湖	16—0.5	13.3	9.8—25			4.6—20.8		马春梅,2006
湖北大九湖	4.7—4.2	13	38					Zhao <i>et al.</i> , 2016
湖北大九湖	15.75—0	3—15	10—25			5—24		朱诚等,2006
湖北大九湖	191—1.1	1—16	5—35			1—25		郑秋凤等,2014
湖北江汉平原	4.5—0		0—8					吴立,2013
湖北屈家岭	6—0.3		0—22			0—15		李宜垠等,2009
陕西洛南	表土		0.4—34.9	1.6		0—2.7		Zhang <i>et al.</i> , 2014
陕西蓝田	早-晚更新世	0—1	1—10					中国科学院植物研究所等,1965
陕西渭南北庄村	27.4—18.4		<5					孙湘君,1989
陕西渭南闫村	300—200		0—10					童国榜等,1988b
陕西华县	早更新世		3.6—36.4					李文漪,1983
秦岭太白山北坡	0.94—0		0—12					童国榜等,1996
河南郑州	5.7—4.4	0.7—1	0.7—11.1					严富华等,1986
山西张村	早更新世	0—5						唐领余,1991
河北桑干河流域	中更新世	0.5	0.5—4.6	0—1.3				唐领余、刘金陵,1984
河北黄骅	10—0		0—10					刘鸿雁等,1994
河北沧县	中更新世		<1					童国榜等,1988a
北京房山坟庄	22.7—3		0—5					孔昭宸等,1982
北京尹家河	8.25		5					孔昭宸等,1982
山东青岛市	7.3—3.5		1.9—36.3	<2		1—6.7		Chen and Wang, 2012
渤海地区黄河口	9.5—7.6		7.3—19.2					陈金霞等,2012
青海清水河	更新世		0—5.7					唐领余、王睿,1976a
昆仑山垭口	更新世		0—8					唐领余、王睿,1976b
可可西里五雪峰	更新世		0—5					黄赐璇,1996
青海沱沱河	早更新世		0—32					孔昭宸、杜乃秋,1981

续表 I

Table I (continued)

地点	年代 (ka BP)	落叶类型(%)			常绿类型(%)			来源
		<i>Fagus</i>	Q. (D)	<i>Cas.</i>	Q. (E)	<i>Cyc.</i>	<i>Cast. /Li.</i>	
青海湖盆地	早更新世		1—3.7					杨惠秋、江德昕,1965
青海湖	16—0		<2					Shen Ji <i>et al.</i> ,2005
青海湖 QH85 孔	11—0		0—0.6	<1				杜乃秋等,1989
青海察尔汗湖	10—1.5		0.3—0.6					杜乃秋、孔昭宸,1983
青海达连海	4—0.5		<5					程波,2006
青海共和盆地	226—10		<2					唐领余、汪世兰,1988
青海柴达木盆地	晚更新世		<1					沈振区等,1988
甘肃海原	13—0		1.1—11.9					孙爱芝等,2008
甘肃静宁	44.2—11		0—10					李春海等,2006
甘肃静远	6.2—0		2—15					Zhao <i>et al.</i> ,2010
甘肃马哈山	8.3—0		0.5—4.5					汪世兰,1988
甘肃大地湾	7.5—5.5		0—10					An <i>et al.</i> ,2004
甘肃定西	3.5		0—5					唐领余等,1990
甘肃民勤灌野泽	9.8—2		<5					Chen <i>et al.</i> ,2006
甘肃民勤三角城	4.7—0		0—3.3					朱艳,2002
宁夏南部	13—7		<2					孙爱芝等,2008
新疆艾比湖	8—1		0—5					文启忠、乔玉楼,1990
新疆乌鲁木齐	晚第四纪		0—5					潘安定,1985
塔克拉玛干塔中井	更新世		0—2					闫顺、许英勤,1990
新疆伊犁河谷	15—0		0—10					姚轶锋等,2015
内蒙古岱海	12.3—1.3		0.4—13.1					Xiao <i>et al.</i> ,2004
内蒙古岱海芦苇场	3—0		0—10					刘鸿雁等,1994
内蒙古萨拉乌苏	49.5—2.3		0—10					孙建中等,1991
内蒙古腾格里沙漠	4.2—2.3		2.1—11.4					马玉贞等,1998
内蒙古柳树湾	11.3—0		0—5					黄赐璇,1991
内蒙古西辽河	10—0		0—3					刘鸿雁、李宜垠,2009
内蒙古呼伦湖	3.5—2		<2					温锐林等,2010
内蒙古呼伦湖	.94—0		0—5					羊向东等,1995
内蒙古扎赉诺尔	11.7—1.15		0.3					孔昭宸、杜乃秋,1981
内蒙古月亮湖	9—1		0—5					伍婧、刘强,2012
辽宁普兰店	10—8		5—60					陈承惠等,1965
吉林靖宇金昌	10—0		10—50					Sun <i>et al.</i> ,1991
吉林辉南孤山屯	13.4—0		5—35					刘金陵,1989
吉林三道老爷府沼泽	10.3—0		5—30					袁绍敏、孙湘君,1990
吉林四海龙湾	16.6—10.6		0—5					Stebich <i>et al.</i> ,2009
黑龙江三江平原泥炭	10.6—0		2—30					夏玉梅,1988
黑龙江镜泊湖	10—0.05		20—40					Li <i>et al.</i> ,2011
黑龙江富拉尔基	更新世		0—0.5					刘敏等,1990

注:Q(D)=Deciduous *Quercus*,Q(E)=evergreen *Quercus*,*Csa.*=*Cstanea*,*Cyc.*=*Cyclobanopsis*,*Csta./Li.*=*Castanopsis/Lithocarpus*。

2 第四纪地层中常见壳斗科主要属花粉形态比较与鉴别

2.1 壳斗科植物花粉的基本形态

根据中国第四纪地层中常见壳斗科花粉化石 6 属 (*Castanea*, *Castanopsis*, *Lithocarpus*, *Cyclobalanopsis*, *Quercus* 和 *Fagus*), 按花粉粒大小、萌发孔和外壁表面纹饰等进行初步比较如下:

1) 花粉粒大小: *Quercus*(D) 花粉粒最大, 常在 30 μm 以上; *Quercus*(E) 花粉粒大小居中, 常在 30 μm 以下; *Cyclobalanopsis* 花粉粒较小, 常在 27 μm 以下; *Castanopsis*, *Lithocarpus* 花粉粒小, 常在 25 μm 以下; *Castanea* 花粉粒最小, 常在 21 μm 以下。

2) 按极面×赤道面的平均大小(μm)从小到大排列如下: *Castanea*(13×9)–(18.3×11)–*Lithocarpus*(14×8)–(18×10)–*Castanopsis*(16.1×10.8)–(19.5×12.7)–*Cyclobalanopsis*(23.1–31.5)×(21–25.2)–*Quercus*(E)(25.2–33.6)×(18.9–29.4)–*Quercus*(D)(27.3–42)×(25.2–37.8)–*Fagus*(39–42)–*Quercus glandulifera*(47.5–58)×(38–49)。

3) 最长极轴/最长赤道轴(μm): *Quercus*(D) 50.4/46.2; *Fagus* 50/39; *Quercus*(E) 33.6/31.5; *Cyclobalanopsis* 31.5/27.3; *Castanopsis* 27.5/18.6; *Lithocarpus* 21/12.1; *Castanea* 20/13.5。

4) 按三孔沟、三拟孔沟和三沟区分, 具三孔沟: *Castanea*, *Lithocarpus*, *Castanopsis*, *Quercus*(E), *Fagus*; 具三拟孔沟: *Cyclobalanopsis*, *Quercus*(E); 具三沟: *Quercus*(D)。

5) 按外壁细网—颗粒—瘤等粗糙程度区分, 不明显细网或颗粒: *Castanea*, *Lithocarpus*, *Castanopsis*; 明显或不明显细颗粒或颗粒小刺: *Quercus*(E), *Cyclobalanopsis*, *Fagus*; 明显粗颗粒, 具扁圆大而明显的小瘤: *Quercus*(D)。

2.2 壳斗科主要属种植物花粉的基本形态比较与鉴别

根据王伏雄等(1995)壳斗科植物花粉形态检索, 比较简单:

1. 花粉粒为长球形, 具三孔沟。体积较小, 最大直径一般小于 21 μm

..... *Castanea*, *Castanopsis*, *Lithocarpus*

1. 花粉粒为扁球形、近球形或长球形, 具三孔沟, 3 内孔不明显或不具内孔。体积较大, 最小

直径一般大于 24 μm。

2. 花粉粒扁球形到近球形, 具三孔沟, 沟短 *Fagus*

2. 花粉粒近球形, 具三孔沟, 内孔不明显或不存在, 沟较长 *Quercus*

从上述检索中可以看出: 1) *Castanea*, *Castanopsis* 及 *Lithocarpus* 3 属不易区分; 2) *Quercus* 属中包含有三拟孔沟、个体相对较小的常绿类型栎类花粉 *Q.*(E), 没有分出。有必要进行进一步检索:

1. 花粉长球形, 具三孔沟, 体积较小, 最大直径一般小于 21 μm。

2. 花粉极轴 14–20 μm, 赤道轴 8.5–13.5 μm。

3. 内孔横长, 处于沟的中间, 内孔与沟相接部分缢缩, 外壁具不明显细网或颗粒状雕纹 *Castanea*

3. 内孔横长, 较大, 表面光滑或具微弱颗粒状雕纹 *Lithocarpus*

2. 花粉极轴 15–21 μm(有时可达 27.5 μm), 赤道轴 10–14 μm(有时可达 18.6 μm), 内孔横长, 沟细长, 末端尖, 在极面相距很近, 外壁具不明显网纹 *Castanopsis*

1. 花粉粒扁球形、近球形或长球形, 具三孔沟或三拟孔沟, 或不具内孔, 体积较大, 最小直径大于 24 μm。

2. 花粉粒扁球形到近球形, 花粉较大(39–42 μm), 具三孔沟, 沟短渐尖, 内孔大, 略带椭圆形, 具孔膜, 孔边外壁稍厚 *Fagus*

2. 花粉粒近球形到长球形, 具三拟孔沟或三沟, 沟较长。

3. 花粉粒多为近球形, 具三沟, 花粉粒较大, 常在 30 μm 以上, 外壁具明显不规则颗粒状, 或具小瘤状雕纹, 轮廓线显著波浪形 *Quercus*(D)

3. 花粉粒长球形或近球形, 具三拟孔沟, 花粉粒较小, 常在 30 μm 以下, 外壁明显或不明显细颗粒或颗粒小刺, 轮廓线平或微波浪形。

4. 花粉粒长球形, 具三拟孔沟, 孔不明显, 外壁具细颗粒 *Cyclobalanopsis*

4. 花粉粒近球形, 具三拟孔沟, 沟较长, 外壁具颗粒小刺状, 外壁轮廓微波浪形 *Quercus*(E)

Castanea, *Castanopsis*, *Lithocarpus*, *Cyclobalanopsis* 和 *Quercus*(E) 花粉形态比较可见表 II, *Quercus*(D), *Quercus*(E) 和 *Cyclobalanopsis* 花粉形态比较可见表 III。

表 II *Castanea*, *Castanopsis*, *Lithocarpus*, *Cyclobalanopsis* 和 *Quercus* (E) 花粉形态比较

Pollen morphological comparison between *Castanea*, *Castanopsis*, *Lithocarpus*, *Cyclobalanopsis* and *Quercus* (E).

形态结构	 10 μm <i>Castanea</i>	 10 μm <i>Lithocarpus</i>	 10 μm <i>Castanopsis</i>	 10 μm <i>Cyclobalanopsis</i>	 10 μm <i>Quercus</i> (E)
形状	长球形,赤道面两端较平 极面三裂圆形	长球形 极面钝三角形	长圆球形,较尖 极面三裂圆形, 有时钝三角形	长球形 极面三裂圆形	球形或近球形 极面三裂圆形
平均大小 (μm)	15.6×10 小(14—20)×(8.5—13.5)	16×19 较小(15—20)×(9—12)	17.8×13.3 居中(15—21)×(10—12)	23.1×12 稍大(13—27)×(10—25)	24.8×22.5 较大(20—23)×(20—22)
萌发孔	三孔沟,孔横长或圆	三孔沟,赤道孔区 稍外凸,沟细长	三孔沟,内孔横长或椭圆, 有空腔	三拟孔沟,沟中段稍收缢, 沟端放开,沟宽长	三拟孔沟或三沟, 孔不明显
纹饰	细密,近光滑	模糊颗粒	细密	细颗粒网或较粗	粗而显著

表 III *Quercus* (D), *Quercus* (E) 和 *Cyclobalanopsis* 花粉形态比较

Pollen morphological comparison between *Quercus* (D), *Quercus* (E) and *Cyclobalanopsis*.

花粉照片	 10 μm <i>Quercus</i> (D)	 10 μm <i>Quercus</i> (E)	 10 μm <i>Cyclobalanopsis</i>
形状	近球形	近球形或近长球形	近球形或长球形
大小	花粉粒最大 常在 30 μm 以上 平均(27.3—42)×(25.2—37.8) μm 极轴最长 50.4 μm 赤道轴最长为 46.2 μm	花粉粒大小居中 常在 30 μm 以下 平均(25.2—33.6)×(18.9—29.4) μm 极轴最长 33.6 μm 赤道轴最长为 31.5 μm	花粉粒最小 常在 30 μm 以下 平均(23.1—31.5)×(21—25.2) μm 极轴最长 31.5 μm 赤道轴最长为 27.3 μm
萌发孔	三沟(少数三拟孔沟)	三拟孔沟(个别三沟),沟较长	三拟孔沟,孔不明显
表面纹饰	明显粗颗粒	明显或不明显细颗粒或颗粒小刺	明显或不明显细颗粒或颗粒小刺
外壁结构	覆盖层具扁大而明显的瘤疣	覆盖层具细圆颗粒或尖小刺矮柱状	覆盖层具细圆颗粒或尖小刺矮柱状

3 壳斗科植物常见属的花粉化石产地及生长地理气候条件

现今壳斗科植物的地理分布,在欧洲分布的北界位于北纬 60° ,在亚洲分布区北界位于北纬 56° ,在北美洲分布的北界位于北纬 50° ,而常绿类型分布区的南缘位于南纬 10° 左右(李建强,1996)。植物现代分布的格局是地质、地理及气候环境长期作用于植物以及植物自身对于环境影响的综合表现,如大陆漂移产生海陆相对位置变化,导致大陆与大陆之间,大陆与沿海的岛屿间,以及岛屿与岛屿分开的间断分布;或是气候变冷,冰川对欧亚大陆的影响很大,使得北纬 35° 以北欧亚广大地区的 *Trigonobalanoidea*, *Lithocarpus* 和 *Castanopsis* 灭绝(李建强,1996)。

3.1 *Castanopsis/Lithocarpus*

Lithocarpus 是壳斗科植物中最原始的属,它与 *Castanopsis* 是近缘属,它们的花粉形态十分相似,其分布区也十分接近,可能 *Castanopsis* 分布较 *Lithocarpus* 更北一些。中国这两个属有 250 余种,绝大多数分布于我国南部和西南部,主要分布于云南、广东和广西,其次是福建和台湾地区。

根据 150 余个研究点的第四纪孢粉记录统计, *Castanopsis* 和 *Lithocarpus* 花粉化石主要产于云南洱海、昆明盆地和广东潮汕平原、珠江三角洲及雷州半岛以及福建南屏和台湾 Taushe 盆地等地的晚更新世以来的地层中。它们在孢粉组合的含量中约占 5%—55%(表 I)。上述产地的分布范围西北界限在西昌—大理—一线地区,约在北纬 26° — 28° ,东南界限在台湾 Taushe 盆地(约在北纬 20° — 25°)以及江苏连云港(24.35° N)。由此可见, *Castanopsis* 和 *Lithocarpus* 花粉化石分布中心范围应该在北纬 20° — 28° ,该范围内气象数据表明其年均气温在 14.9°C 至 23.5°C ,年均降水量在 $1\,000$ — $1\,700$ mm。北界年均温约在 15°C ,年均降水量在 $1\,000$ mm,这就是说 *Castanopsis* 和 *Lithocarpus* 的生长气候要求大约是年平均气温不低于 15°C ,年降水量不少于 $1\,000$ mm。

3.2 *Castanea*

Castanea 与 *Castanopsis* 和 *Lithocarpus* 之间具有极密切的亲缘关系,是 *Castanopsis* 的近缘属,

分类学家们将这 3 属归于栗亚科(subfamily *Castaneoides*),但 *Castanea* 为落叶树种,与常绿树种 *Castanopsis* 和 *Lithocarpus* 是有区别的。*Castanea* 在欧亚大陆分布最为广泛。该属中国有 3 种,大多分布于秦岭以南的广大山区,其分布范围北界为黑龙江西部(北纬 50°),西北至甘肃南部,东至台湾,南界为我国广州近郊(北纬 23°)。大多生长于海拔 $1\,800$ m 以下山地,常与落叶阔叶树混生。最早可靠的 *Castanea* 花粉化石产于美国田纳西州始新世中期地层(Crepet and Nixon,1983; Jones,1984),说明 *Castanea* 在渐新世或中新世在欧亚、北美都有分布,之后受第四纪冰期的反复影响,不能适应干旱和寒冷的气候条件,而局限分布于亚热带与暖温带湿润的气候环境中,只能分布在北美西北、亚洲西部和欧亚大陆北部。

Castanea 花粉形态与 *Castanopsis* 和 *Lithocarpus* 不易区分,在白垩纪—新近纪地层中将三者定为栗粉属 *Cupuliferted*。在我国从白垩纪至古近纪古新世到新近纪上新世地层中也有着丰富的栗粉属化石,分布区从南海北部(孙湘君等,1981)、广东南海县、广西南明、昌墩、上思(Wang,1993)到辽宁盘山的广大地区,西部至新疆(宋之琛等,1986)。

我国第四纪地层中 *Castanea* 已按自然命名法定名,均定为 *Castanea*,由于与 *Castanopsis* 难以区别,有的研究者可能将一部分归入 *Castanopsis* 或 *Quercus*。所以在我们调查的 150 多个点第四纪孢粉记录中出现频率并不高,仅在香港大亚湾、云南昆明盆地、松华盆地和勐遮盆地、贵州大干堤和梵净山、广西钦州、台湾 Taushe 盆地、浙江宁波平原、上海地区、苏北扬州、建湖和连云港等研究区中花粉化石含量较高一些,约占孢粉总数的 3%—40%(表 I)。另外,陕西洛南、河北桑干河流域、青岛市以及青海湖地区也有少量出现(唐领余、刘金陵,1984;杜乃秋、孔昭宸,1989; Chen *et al.*, 2009; Zhang *et al.*, 2014)。从上述资料可以看出, *Castanea* 花粉化石分布北界较 *Castanopsis* 和 *Lithocarpus* 要向北迁移 10 个纬度,达北纬 36° ,说明 *Castanea* 较 *Castanopsis* 和 *Lithocarpus* 更适应温带气候条件,即适应于年降水量 700 — $1\,700$ mm,年均气温 13°C — 23°C 较大幅度范围的气候条件生长。

3.3 *Quercus*

Quercus 植物约有 50 多种,是北半球亚热带—温带常绿—落叶阔叶林的优势树种,分布最为广泛,

几乎遍布欧亚大陆及北美洲,最北到北欧北纬 60°,向东南经西亚、蒙古、中国、日本到朝鲜,最南端达爪哇岛,约南纬 8°,在我国 *Quercus* 分布是以云南为中心向四周分布。*Quercus* 植物是夏绿或常绿乔木,少数为灌木。根据《中国植物志》记载,*Quercus* 实际存在 3 大类群,即青冈类、落叶栎类和高山栎类,前者独立成 *Cyclobalanopsis*,其余均归 *Quercus*。它们的花粉形态以花粉粒近球形或近长球形、三沟或三拟孔沟和表面具颗粒状纹饰为主要特征。我们在第四纪花粉研究中往往将花粉粒近球形,具三沟,颗粒较粗,个体粒径大于 30 μm 的化石鉴定为落叶栎 *Quercus*(D),大多产于华北、东北和华东等地;将三拟孔沟,颗粒较细,个体粒径小于 30 μm 的花粉化石鉴定为常绿栎 *Quercus*(E),多产于西南高山地区。本节叙述的是落叶栎类。

栎粉属 *Quercoidites* 是一个与现存 *Quercus* 植物花粉十分相似的花粉化石,在我国云南、广东、江苏、湖北等地的晚白垩世地层及江西、辽宁北部、东北、雷州半岛、海南岛等地的古近纪地层中有 *Quercoidites* 化石的记录。到第四纪,*Quercus* 花粉化石按自然命名法定名 *Quercus*,全国各地均有发现,从南海南部(约南纬 5°)到黑龙江北部(约北纬 50°),包括台湾和香港地区都出现该属花粉化石,其中花粉含量较高的是在南方和西南以及东北三省,如雷州半岛田洋 *Quercus* 占花粉总数的 10%—47%,云南松华,昆明盆地达 5%—35%,四川冕宁达 5%—38%,台北平原达 13%—50%,湖北神龙架达 30%—50%,吉林静宇达 10%—50%,黑龙江镜泊湖达 20%—40%等(表 I)。由此可见,*Quercus* 花粉化石的存在反映 *Quercus* 植物生长的生态幅度较 *Castanopsis* 和 *Lithocarpus* 宽得多,基本的生长气候范围在年均温 3.5 $^{\circ}\text{C}$ —23 $^{\circ}\text{C}$,能够忍受 1 月份低于 -10 $^{\circ}\text{C}$ 的寒冷,也能够经受 7 月份近 30 $^{\circ}\text{C}$ 的高温考验,年均降水量约 500—1 700 mm。根据刘茂松、洪必恭(1998)对 *Quercus* 物种丰富度回归分析研究,影响 *Quercus* 物种丰富度分布的主要有年降水、最低温度、有冰月数、大陆度等负相关因数及 1 月均温的正相关因子,反映对 *Quercus* 分布的影响因素较多,关系也较复杂。

3.4 *Quercus*(E)(表 IV)

我国第四纪地层中经常发现一些与 *Quercus* 相似的花粉化石,但是它们个体较小(粒径 < 30 μm),具三拟孔沟与个体较大具三沟的 *Quercus* 有区别。

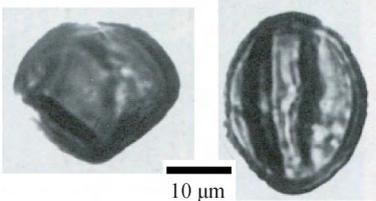
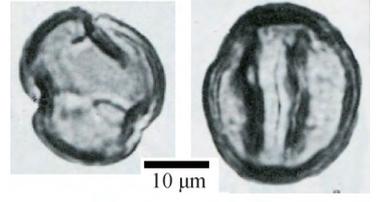
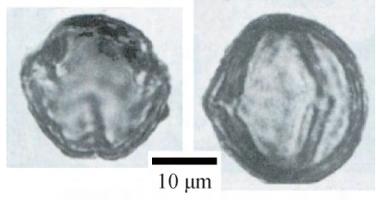
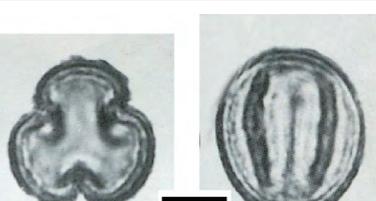
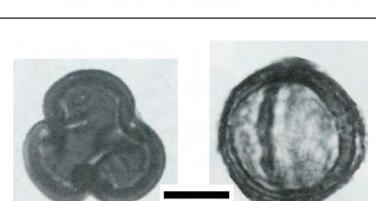
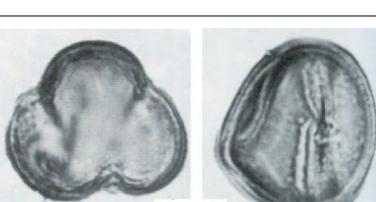
我们将它们归于 *Quercus* 的常绿类型,通常是定名为 *Quercus*(E)。*Quercus* 植物中常绿类型树种,一部分是分布于热带、亚热带到暖温带的山地乔木或灌木,它们起源于泰国北部、云南南部和西南部。其分布中心在中国的横断山地区,川西、滇西南及藏东南等高山地区(李建强,1996;周浙昆,1999),如滇栎(*Q. schotthkyana*),中华栎(*Q. sinensis*)生长在云南、贵州、四川的 1 500—2 000 m 山地。常绿栎类型花粉化石在云南星云湖、泸沽湖、天才湖及高黎贡山,贵州梵净山,四川螺髻山等地第四纪地层中均有发现。这类植物生长的气候条件一般为:年降水量在 1 000—1 500 mm,年均温在 10 $^{\circ}\text{C}$ —17 $^{\circ}\text{C}$ 左右。另外,少部分种类在我国东部山地如台湾阿里山,福建戴云山的全新世沉积中也有常绿栎类型花粉化石发现。

常绿栎类型中有一部分为硬叶常绿阔叶的乔木或灌木,主要分布于我国西南的高山地区,即川西、滇西南、藏东南及吉隆、亚东等地。一般生长的气候条件为年降水量在 600—1 000 mm,如冬青栎(*Q. ilex*)分布在北纬 26°—30°,东经 103°以西的海拔 2 500—4 000 m,是西南地区特有的森林植被成分;川滇高山栎(*Q. aquifolioides*)分布于川西、滇西北及藏东南,从沟谷向上个体从乔木到矮乔木,再到灌木。这种变化是生长条件寒冷,多风及土壤贫瘠和强紫外线的结果;高山栎(*Q. semearpteria*)分布于吉隆到亚东海拔 2 500—3 900 m。该种为阳性树种,需年降水量 900—1 000 mm,年均温在 15 $^{\circ}\text{C}$ 左右。还有像川西栎(*Q. gilliana*)、光叶高山栎(*Q. rchderiana*)等和以上常绿硬叶栎类花粉一样,它们都是个体较落叶栎小、具三拟孔沟、极轴 \times 赤道轴为 20.5 \times (20—23) μm 、表面纹饰较粗糙的特征。

3.5 *Cyclobalanopsis*(表 V)

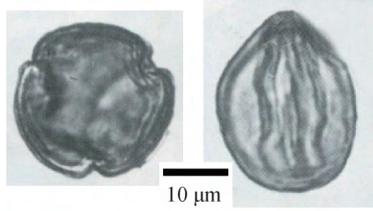
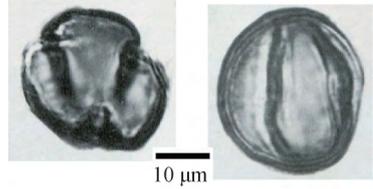
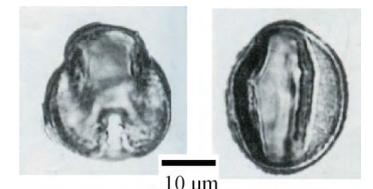
Cyclobalanopsis 常被当作 *Quercus* 的一个亚属,但其有不同于 *Quercus* 的分布特征,其分布较 *Quercus* 偏南,在东南亚地区的亚热带到热带山地森林中较普遍,中国南部和西南以及中南半岛是 *Cyclobalanopsis* 的现代分布中心。其北界一般在秦岭—淮河以南,东至福建、台湾,南自海南、两广、云南。就该属种类数量而言,在广西、云南和广东最多,其次为贵州、海南、福建和台湾地区,西北青海、甘肃仅有一、两种生长。如产于云贵川及两广的滇青冈(*Cy. glauoides*)、曼青冈(*Cy. oxyodon*)和环

表IV *Quercus*(E)中几个种的花粉形态及其产地、生境
Pollen morphology, producing area and habitat of some species of *Quercus*(E).

种名	产地	生境	花粉形态	花粉照片*
巴东栎 <i>Quercus engleriana</i>	陕西、江西、福建、河南、湖北南部、广西、四川、贵州、西藏等地	生于海拔 700—2 700 m 山坡、山谷疏林中	(25. 2—28. 2)×(21—25. 3) μm 三拟孔沟 纹饰不明显	
锥连栎 <i>Q. coccoferoides</i>	海南、广西、贵州、云南等地	生于海拔 1 000—2 600 m 山地或松林中	(25. 2—27. 3)×(23. 1—26. 3) μm 三拟孔沟和三沟 明显颗粒	
铁橡栎 <i>Q. franchetii</i>	四川、云南(金沙江、南盘江)等地	生于海拔 1 000—2 500 m 山地阳坡或干旱河谷	(21. 2—27. 8)×(19. 8—23. 1) μm 三拟孔沟 微弱颗粒	
乌冈栎 <i>Q. phillyraeoides</i>	长江中下游各省区、陕西及滇东南地区	生于海拔 1 000—1 700 m 阳处山脊上, 抗旱耐瘠薄	(24—29. 6)×(16—23. 1) μm 三拟孔沟 颗粒疣状	
高山栎 <i>Q. semecarpifolia</i>	西藏等地	生于海拔 2 600—4 000 m 山地、山谷栎林或松栎林中	(25. 2—29. 4)×(23. 1—25. 2) μm 三拟孔沟 不规则颗粒状	
川滇高山栎 <i>Q. aquifolioides</i>	四川、云南、贵州、西藏等地	生于海拔 2 000—4 500 m 山坡向阳处或高山松林下	(23. 1—25. 2)×(23. 1—24) μm 三拟孔沟 粒状	
川西栎 <i>Q. gilliana</i>	甘肃南部、四川、云南、西藏等地	生于海拔 1 500—3 100 m 强光寒旱、抗风贫瘠土壤中	(31. 3—32)×(25. 2—29. 4) μm 三拟孔沟 颗粒小刺状	

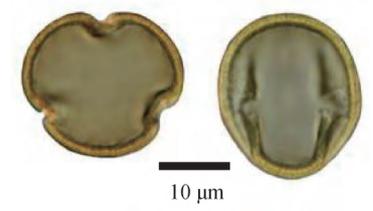
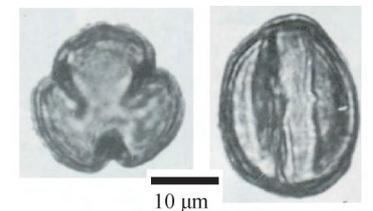
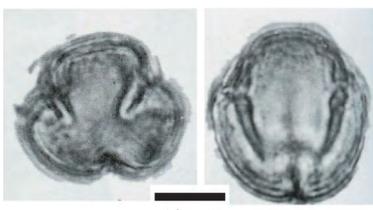
续表 IV

Table IV (continued)

种名	产地	生境	花粉形态	花粉照片*
黄背栎 <i>Q. pannosa</i>	云南大姚、宾川、 下关、鹤庆、丽 江、中甸等地	生于海拔 2 500—3 000 m 开旷山坡, 栎林或 松林中	(27. 3—31. 5)×(21—29. 4) μm 三拟孔沟 细密明显颗粒	
灰背栎 <i>Q. senescens</i>	四川、云南、贵 州、西藏等地	生于海拔 1 900—3 300 m 向阳石灰岩山地松 林中	(29. 4—33. 6)×(21—25. 2) μm 三沟和三拟孔沟 细密颗粒小刺状	
毛脉高山栎 <i>Q. rehderiana</i>	四川、云南、贵 州、西藏等地	生于海拔 2 000—4 500 m 向阳山坡, 为高山 常绿硬叶树种	(23. 1—27. 3)×(19—24. 1) μm 三拟孔沟和三沟 颗粒或颗粒小刺状	

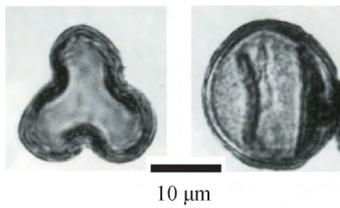
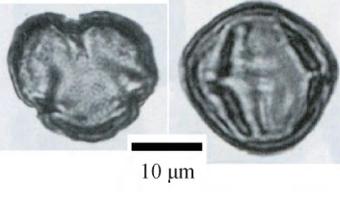
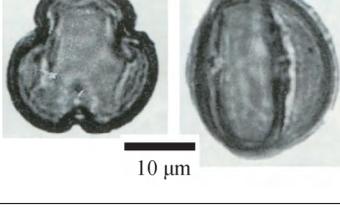
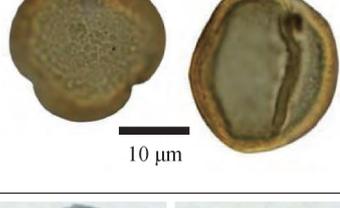
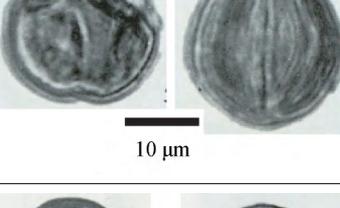
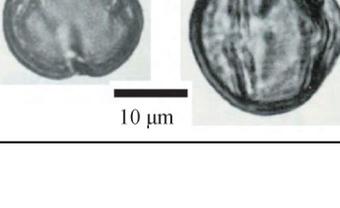
* 本表中照片除乌冈栎花粉由毛礼米提供外, 均引自王萍莉、溥发鼎, 2004。

表 V *Cyclobalanopsis* 一些种的产地、生境与花粉形态Pollen morphology, producing area and habitat of some species of *Cyclobalanopsis*.

种名	产地	生境	花粉形态	花粉照片*
青冈 <i>Cyclobalanopsis glauca</i>	陕西、甘肃、江 苏、浙江、安徽、 江西、福建、台 湾、河南、湖南、 广西和广东北 部、四川、西藏、 贵州等地	生于海拔 60—2 600 m 山坡沟谷常绿/落 叶阔叶林中	(23. 1—25. 2)×(21—23. 1) μm 三拟孔沟 不明显颗粒	
毛叶青冈 <i>Cy. kerrii</i>	海南、广西、贵 州、云南等地	生于海拔 160—1 800 m 山地疏林中	(24—27. 3)×(21—25. 3) μm 三拟孔沟和三沟 明显颗粒	
滇青冈 <i>Cy. schothyana</i>	四川、贵州等地	生于海拔 1 500—2 500 m 中山陡坡石灰岩 山地	(23. 1—27. 3)×(21—25. 3) μm 三拟孔沟 细密颗粒小刺	

续表 V

Table V (continued)

种名	产地	生境	花粉形态	花粉照片*
曼青冈 <i>Cy. oxyodon</i>	陕西、浙江、江西、湖北、湖南、广东、广西、云南、贵州、四川、西藏等地	生于海拔 700—2 800 m 山坡、山谷杂木林中	(21—23. 2)×(21—23. 2) μm 三拟孔沟 颗粒疣状	
云山青冈 <i>Cy. sessilifolia</i>	江浙、江西、福建、台湾、湖北、湖南、广东、广西、四川、贵州等地	生于海拔 1 000—1 700 m 山地杂木林中	(21. 5—25. 1)×(22—24. 1) μm 三拟孔沟 颗粒状	
岭南青冈 <i>Cy. championii</i>	福建、台湾、海南、广东、广西、云南等地	生于海拔 100—1 700 m 森林中	(23—25. 2)×(19. 4—23. 3) μm 三拟孔沟 颗粒和颗粒小刺	
多脉青冈 <i>Cy. multinervis</i>	安徽、江西、福建、湖北、湖南、广西、四川等地	生于 1 200—2 000 m 山地上部	(23. 1—25. 2)×(21—23. 1) μm 三拟孔沟和三沟 细密颗粒小刺状	
细叶青冈 <i>Cy. ciliaris</i>	河南、陕西、甘肃、江苏、浙江、安徽、江西、福建、湖北、湖南、广东、广西、四川、贵州等地	生于海拔 500—2 600 m 山地杂木林中, 或青冈林上部	(21—25. 8)×(19—24) μm 三拟孔沟 明显颗粒网	
窄叶青冈 <i>Cy. auqustinii</i>	广西、贵州、云南等地	生于海拔 1 200—2 700 m 阳坡或半阴坡, 干湿季明显地区	(18. 9—25. 2)×(18. 9—23) μm 三拟孔沟 颗粒小刺状	
小叶青冈 <i>Cy. myrsinaefolia</i>	陕西、河南南部、福建、广西、四川、云贵等地	生于海拔 2 000—2 500 m 山谷阴坡杂木林中	(21—23. 1)×(19. 3—23. 1) μm 三拟孔沟 颗粒及颗粒小刺	

* 本表中照片除青冈和细叶青冈花粉由毛礼米提供外, 均引自王萍莉、薄发鼎, 2004。

带青冈(*Cy. annulota*);江浙闽赣等地的大叶青冈(*Cy. jenseniana*)、云山青冈(*Cy. sessilifolia*)和细脉青冈(*Cy. multinervis*);华南港台地区的青冈栎(*Cy. glauca*)、岭南青冈(*Cy. championii*)和台湾青冈(*Cy. movii*)等(王萍莉、溥发鼎,2004.),所有这些青冈的现代花粉形态,因花粉长球形或扁球形、具三孔沟或三拟孔沟、极轴×赤道轴为 $20.5 \times (20-12) \mu\text{m}$ 及表面纹饰近光滑—较粗糙,而与栎类花粉有较大区别。其中台湾产(Huang,1992)的青冈栎(*Cy. glauca*)和毬子栎(*Cy. paucidentata*),个体相对较大,分别为 $(13-27) \times (10-25) \mu\text{m}$ 和 $(22-27) \times (25-30) \mu\text{m}$ 。

根据不完全统计,中国第四纪地层中发现的*Cyclobalanopsis*花粉化石主要在南海南部和雷州半岛(含量约占孢粉总数的5%—15%)、广东和香

港地区(5%—25%)、川西地区(5%—30%)、福建和台湾地区(5%—35%)以及江浙沪地区(5%—20%),到陕西秦岭含量不到3%,再向北未发现该属(表I)。依据*Cyclobalanopsis*的现代植物分布范围以及*Cyclobalanopsis*花粉化石的产地,*Cyclobalanopsis*应该生长在秦岭—淮河一线以南。秦岭—淮河一线以南是中国具有重要地理意义的气候界线:是中国1月份 0°C 等温的分界线;是中国年降水量800mm的分界线;是中国半湿润与湿润的地理分界线;是中国落叶阔叶林分布区与常绿阔叶林分布区的分界线。这就清楚表明,*Cyclobalanopsis*生长的地理气候条件要求是1月份气温不低于 0°C ,年均温在 8°C — 15°C 以上,年降水量不少于800mm,为温暖湿润的生态环境(表VI)。

表 VI *Fagus* 和 *Cyclobalanopsis* 化石产地、化石含量、地区的气候地理数据和现生种数(李建强,1996;刘茂松、洪必恭,1998)
Producing area and content of *Fagus* and *Cyclobalanopsis* fossil Pollen with climatic and geographic characters(after Li, 1996;Liu and Hong, 1998)

产地	所属省地	海拔(m)	年降水量(mm)	年均温($^{\circ}\text{C}$)	<i>Cyclobalanopsis</i>		<i>Fagus</i>	
					现生种数	化石含量	现生种数	化石含量
珠江三角洲	广东	11	1 696.5	21.9	26	3	1	2.7
潮州平原			2 429	21.4		10.4		
黄茅海			1 696.5	21.9		5—30		
香港地区	香港地区	32	2 214	22.9		5—25		<2
云南星云湖	云南	1 720	879.1	15	35	5—25	2	5
昆明盆地		1 891	1 006.7	14.5		10		0—10
洱海盆地		2 052	1 478	14.9		0—5		
贵州大干坝	贵州	1 310	1 436	14.1	50	2—20	2	5—20
重庆	重庆	2 104	1 125.3	17.5	11		5	3.8—5.9
福建戴云山	福建		1 800	17.5	14	5—20	2	0.4
台北盆地	台湾地区	9	2 515	21	17	2—20	1	3—38
江西赣北	江西	841	1 400	17	12		2	0—8
江苏溧水	江苏	8.9	1 079.4	15.6	3		2	0—10
安徽巢湖	安徽	450	995.7	16.1	6	4.9—37.2	4	0.5
湖北大九湖	湖北	1 700	1 560	7.4	11	4.6—20.8	3	13.3
陕西蓝田	陕西	470	740	13	5		2	0—1
河南郑州	河南	110	649.9	14.2	2		1	0.7—1

3.6 *Fagus*

Fagus 是欧亚—北美间断分布的温带类型植物,分布区的北界位于挪威和瑞典南部约北纬 60° ,并向南分布到地中海沿岸,向东分布到西亚的伊朗,经中亚间断分布进入中国后集中分布于华中和华东

地区海拔700—2 300 m的山地。从西藏东南部、云南东北部、南岭以北到黄河以南地区,向东分布到台湾及日本,其分布区的南界在越南北部的沙坝(李建强,1996)。中国分布于秦岭以南、五岭南坡以北各地,西南自西藏东南至南岭以南,北至黄河以南,东到台湾。生长于海拔300—2 400 m山地杂木林阳

坡,常与常绿或落叶树混生(表VI)。如华东地区的台湾水青冈(*F. hayatae*)和光叶水青冈(*F. laci-da*);华中地区的钱氏水青冈(*F. chinii*),巴山水青冈(*F. gayatae* subsp. *pashanica*)等(王萍莉、溥发鼎,2004)。

山毛榉粉属(*Fagus pollenites* Raatz)是中国最早发现于广东和江苏的白垩纪—古近纪的 *Fagus* 的花粉化石,其形态与现生植物 *Fagus* 花粉相近似,为圆形三孔沟,孔大而近圆,大小 41—48 μm ,表面具较粗颗粒。植物关系属壳斗科山毛榉属(*Fagus*)(宋之琛等,1999)。现代植物 *Fagus* 花粉近扁球形—扁圆球形,极面观三裂圆形,大小为(26.6—47.5)×(28.5—53.2) μm ,具三(四)孔沟,沟细长,末端尖或钝圆,孔大近圆形,具沟膜,表面具网或细脑纹状纹饰。如分布较广的米心水青冈(*F. engie-riana*),产自云南东北部、四川、陕西秦岭以南、湖北西部和安徽黄山,生长于海拔 1 200—2 500 m 山坡(表VI)。该种花粉扁圆形,极轴为 34.2×36.1 μm ,具三孔沟,沟宽约 3—4 μm ,孔圆形,具厚缘;产自我国台湾的台湾水青冈(*F. hayatae*)的花粉是壳斗科中个体较大的一种,大小为(36—42)×(39—45) μm ,最长轴可达 50 μm ,花粉扁球形到近球形,具三孔沟,沟短渐尖,内孔大具膜,表面具颗粒状雕纹(王伏雄等,1995);又如,分布于长江以南各省、安徽和陕西西部,生长于海拔 1 000—2 500 m 山坡阴湿处的水青冈(*F. longipetiolata*)因个体较大[(40—47.5)×(41.8—53.3) μm]、沟细长、长轴与沟平行及表面具细脑纹状纹饰而与上述两种稍有区别。

中国第四纪地层中 *Fagus* 花粉化石主要发现于华南、华中和华东地区中更新世以来的沉积中。如广东潮汕平原和黄茅海地区的 50 Ka BP 以来的沉积中,*Fagus* 花粉化石的含量分别达孢粉总数的 3%—10%和 5%—30%;云南昆明盆地和洱海盆地中更新世地层中达 0—15%和 0—5%;贵州和广西地区含量可达 5%—20%;川西和重庆地区全新世沉积中含量达 3%—6%;台湾地区中更新世以来含量较高,达 3%—38%;湖北至江苏一带 190 ka BP 以来含量达 1%—16%。再向北到陕西秦岭一带就很少出现,含量不超过 1%(表I)。

4 总 结

1) 中国各省、自治区及台湾地区的第四纪地层

中发现壳斗科花粉化石有 6 属: *Castanea*, *Castanopsis*, *Lithocarpus*, *Cyclobalanopsis*, *Fagus* 及 *Quercus*, 后者还分出含常绿栎类 *Quercus* (E) 和落叶栎类 *Quercus* (D) 两种类型。对花粉形态相似的 *Castanea*, *Castanopsis* 和 *Lithocarpus* 3 属, 以及 *Cyclobalanopsis* 和 *Quercus* (E) 花粉, 从花粉粒形状和大小、萌发孔数量和形状、极面×赤道面的平均大小、最长极轴与最长赤道轴比以及外壁表面纹饰等多方面进行详细数值对比和照片对照, 提出鉴定特征如下:

a. 花粉粒为长球形, 具三孔沟, 体积较小, 最大直径一般小于 21 μm , 定为 *Castanea*, *Castanopsis*, *Lithocarpus*。其中, *Castanea* 花粉最小, 极轴为 14—20 μm , 赤道轴为 8.5—13.5 μm , 沟细长, 内孔与沟相接部分缢缩。而 *Castanopsis* 沟细长, 末端尖, 在极面相距很近。*Lithocarpus* 与 *Castanopsis* 非常相似, 仅赤道轴稍短, 表面具微弱颗粒而区别与 *Castanopsis*;

b. 花粉粒为扁球形、近球形, 具三孔沟, 孔圆大, 沟短, 体积较大(36—45 μm), 最小直径一般大于 24 μm 定为 *Fagus*;

c. 花粉粒近球形、球形, 极面观三裂圆形。具三沟、三拟孔沟, 内孔不明显或不存, 沟较长, 极轴为 19.5—58 μm , 赤道轴为 8.5—13.5 μm 。表面具颗粒状或小瘤状纹饰, 轮廓线为明显波浪形者定为 *Quercus*。而花粉粒为长球形, 具三拟孔沟, 个体大小在 30 μm 以下, 表面具微弱颗粒者, 或较平滑者定为 *Cyclobalanopsis*。

2) 现今壳斗科植物间断分布于欧亚大陆和美洲大陆的热带亚热带地区, 这种分布格局是地质、地理及气候环境长期作用于植物以及植物自身对于环境影响的综合表现。根据不完全统计, 中国 150 多个第四纪孢粉研究点发现壳斗科花粉化石 6 属, 反映了不同的地理气候环境:

a. *Castanopsis* 和 *Lithocarpus* 花粉化石分布中心范围在北纬 28°—20°, 反映该两属生长气候条件要求大约是年平均气温不低于 15 °C, 年降水量不少于 1 000 mm;

b. *Castanea* 花粉化石分布北界达北纬 36°, 说明该属适应于年降水量 700—1 700 mm, 年均气温 13 °C—23 °C 的气候条件;

c. *Quercus* 花粉化石在全国各地均有发现, 南至南海南部(约南纬 5°), 北到黑龙江北部(约北纬 50°), 反映该属生长的生态幅度较 *Castanopsis*/

Lithocarpus 宽得多,基本的生长气候范围在年均温 3.5 °C—23 °C,同时既能够忍受 1 月份低于 -10 °C 的寒冷,也能够经受 7 月份近 30 °C 的高温考验,年均降水量约 500—1 700 mm;

d. *Quercus*(E)分布中心在中国的横断山地区,川西、滇西南及藏东南等高山地区,海拔 1 500—3 900 mm,北界在北纬 26°—30°,适宜生长的气候条件为年均温 10 °C—17 °C,年降水量 600—1 000 mm;

e. *Cyclobalanopsis* 花粉化石的产地在秦岭—淮河一线以南,该属生长的地理气候条件要求是 1 月份气温不低于 0 °C,年均温在 8 °C—15 °C,年降水量不少于 800 mm,即为温暖湿润的生态环境;

f. *Fagus* 花粉化石主要发现于华南、华中和华东地区中更新世以来的沉积中,最北到陕西秦岭一带就很少出现,主产于湖北神农架和台北盆地,该属生长的地理气候条件要求与 *Cyclobalanopsis* 相近。

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POLLEN MORPHOLOGY OF FAGACEAE IN QUATERNARY DEPOSITS OF CHINA AND ITS RELATIONSHIP WITH CLIMATIC AND GEOGRAPHIC CHARACTERS

TANG Ling-yu¹⁾, LI Chun-hai²⁾, ZHANG Xiao-ping³⁾, SHAO Jian-wen³⁾,
ZHOU Zhong-ze⁴⁾ and LING Chao-hao²⁾

1) Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences, Nanjing 210008, China;

2) Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences, Nanjing 210008, China, chhli@niglas.ac.cn;

3) College of Life Sciences, Anhui Normal University, Wuhu 241000, Anhui, China, pinghengxu@sina.com;

4) School of Resources and Environmental Engineering, Anhui University, Hefei 230000, China

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Abstract

The fossil pollen in the Family Fagaceae, a dominant forest tree group in China flora, is one of the most abundant pollen records in angiosperms of different geological stages since the Tertiary for a long time. According to our preliminary statistics, six genera of Fagaceae fossil pollens were found in China Quaternary strata, including *Castanea*, *Castanopsis*, *Lithocarpus*, *Cyclobalanopsis*, *Fagus* and *Quercus*, with the latest genus, *Quercus*, being classified into evergreen oak *Quercus* (E) and deciduous oak *Quercus* (D). In this paper, the fossil pollens from three genera *Castanea*, *Castanopsis* and *Lithocarpus*, which are similar in pollen morphology, together with those from *Cyclobalanopsis* and *Quercus* (E), were collected for detailed comparisons in quantitative diagnostic features and qualitative photo characteristics (e. g. pollen grain shape and size, aperture number

and shape, average size of polar plane versus equatorial plane, the ratio of the longest polar axis to the longest equatorial axis, and extine ornamentation). The study is to present the key characteristics of pollens in Fagaceae so as to raise the accuracy of identification for the fossil pollens. On the basis of the data above, the climatic conditions and ecological environment where Chinese oak occurred were also discussed. The results show that the distribution center of the fossil pollen in *Castanopsis* and *Lithocarpus* are located between 28°N and 20°N, indicating that the above two genera might prefer to grow in the climate with annual average temperature not lower than 15 °C and annual precipitation not less than 1 000 mm, while the fossil pollens of the other two genera, *Cyclobalanopsis* and *Fagus*, were found in the south of the Qinling Mountains-Huaihe River line, demonstrating that these two taxa adapt to live in warm and humid ecological environment, characteristic of January temperature higher than

0 °C, annual average temperature above 8 °C—15 °C, and annual rainfall higher than 800 mm. However, *Castanea* and *Quercus* fossil pollens are scattered throughout the country, with its distributed range extending up to the northern latitude of 36°—50°, which implicates the two taxa harbor wider ecological amplitude compared with *Castanopsis* and *Lithocarpus*. These two genera could grow if the climate condition meets with the annual average temperature between 3.5 °C to

23 °C, and annual average rainfall between 500 mm and 1 700 mm. Noticeably, both of them are able to endure and survive in the extremely cold temperature of lower than -10 °C and particularly hot temperature of up to 30 °C. We hope this study could provide some authentic basic data concerning of climate and geological environment for improving research of reconstruction of the Quaternary paleovegetation and paleoenvironment history.