



中国双缘衣属(双缘衣科)地衣一新种

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摘要: 现分类系统中, 双缘衣属隶属于子囊菌门, 茶渍纲, 厚顶盘亚纲, 文字衣目, 双缘衣科。全世界有 48 种, 被确认为单系类群的小属。利用形态学、解剖学、生物化学以及分子生物学方法, 对采自天山西部的双缘衣属地衣标本进行分类学研究, 发现了双缘衣属地衣 1 个新种: 绿盘双缘衣 *Diploschistes viridis* (属于双缘衣亚属)。基于最大似然分析(ML)和贝叶斯分析(BI)构建了基于 ITS 位点系统发育树, 详细描述该种的形态特征、分布及栖息地等情况, 并提供了地衣体的彩色图片。

关键词: 双缘衣属; 坛状子囊盘; 系统发育; 单系群; 茶渍酸

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A new species of the lichen genus *Diploschistes* from China

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Abstract: The lichen-forming genus *Diploschistes* belongs to Ascomycota, Lecanoromycetes, Ostropomycetidae, Graphidales, Diploschistaceae. This genus includes 48 crustose species worldwide, and is confirmed as monophyletic group. Based on morphological, anatomical and chemical observation combined with phylogenetic analysis of ITS, a new species of *Diploschistes*, *D. viridis* (referring to subg. *Diploschistes*), is found and described from western Tianshan Mountains. Detailed morphological descriptions, illustrations, habitat and color photos of this species are provided, and an ITS phylogenetic tree was constructed by maximum likelihood (ML) and Bayesian inference (BI) method.

Keywords: *Diploschistes*; urceolate apothecia; phylogeny; monophyletic; lecanoric acid

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双缘衣属 *Diploschistes* Norman 是 1852 年建立的, 当时放在了疣孔衣科 Thelotremataceae Stizenb 中。但在该科与相关地衣科属的研究中发现, 疣孔衣科与文字衣科在地衣体外部形态与内部构造和囊间组织、子囊、子囊孢子的形态上有许多相似之处, 难以找到这 2 个科的区别。唯一区别在于疣孔衣科子囊盘为圆状, 而在文字衣科中为线状子囊盘; 根据子囊器形态的不同, Henssen & Jahns (1973) 和 Henssen (1976) 把疣孔衣科 Thelotremataceae 和文字衣科 Graphidaceae Dumort 分别放在了疣孔衣亚目 Ostropineae Nannfeldt 和文字亚目 Graphidineae Zahlbr 中。近几年的关于厚顶盘目的系统学研究过程发现, 疣孔衣科是单系类群, 但是嵌入到文字衣科中, 与其构成并系关系 (Martín *et al.* 2003; Grube *et al.* 2004; Lücking *et al.* 2004; Staiger *et al.* 2006; Lumbsch *et al.* 2014)。Mangold *et al.* (2008) 在大量的分子数据基础上, 进一步证明了疣孔衣科和文字衣科的关系, 并建议疣孔衣科放在文字衣科内。在 2010 年的《子囊菌大纲》(Outline of the Ascomycota) 中采用了这个分类系统 (Lumbsch & Huhndorf 2010)。后来, 一些学者利用分子生物学手段对文字衣科 Graphidaceae 进行了深入的分系统学研究。Lücking *et al.* (2013) 与 Rivas Plata *et al.* (2013) 进一步将文字衣亚科分为 3 个族 (tribe): 文字衣族 Graphideae Rivas Plata, Lücking & Lumbsch、疣孔衣族 Thelotremateae Rivas Plata, Lücking & Lumbsch 和点衣族 Ocellularieae Rivas Plata, Lücking & Lumbsch, 并把双缘衣属 *Diploschistes* 作为一支放在了文字衣族 Graphideae 里。随后, Lumbsch *et al.* (2014) 在文字衣亚科增加了 4 个新族: Acanthothecieae Lumbsch, Kraichak & Lücking、双缘衣族 Diploschisteeae (Zahlbr.) Lumbsch, Kraichak & Lücking、麻衣族 Leptotremateae Lumbsch, Kraichak & Lücking 和 Wirthiotremateae Lumbsch, Kraichak & Lücking。Kraichak *et al.* (2018) 和 Lücking (2019) 利用时间

条带法 (temporal banding approach) 分别对茶渍纲 Lecanoromycetes O.E. Erikss. & Winka 内两个主要亚纲的几个目进行了深入研究, 其结果把文字衣科 Graphidaceae 裂成双缘衣科 Diploschistaceae Zahlbr、裂隙衣科 Fissurinaceae B.P. Hodk、文字衣科 Graphidaceae *s.str.* 和疣孔衣科 Thelotremataceae 4 个科, 并重新使用了双缘衣科 Diploschistaceae 和疣孔衣科 Thelotremataceae。在 Wijayawardene *et al.* (2022) 发表的真核微生物菌物界的最新分类体系《真菌和类真菌分类群概述》(Outline of Fungi and Fungus-like Taxa) 中采用了这个分类系统。

现在的分类系统中, 双缘衣属属于双缘衣科、文字衣目、厚顶盘亚纲、茶渍纲、子囊菌门, 全世界有 48 种 (Kirk *et al.* 2008; Pérez-Vargas *et al.* 2012; Fernández-Brime *et al.* 2013; Abbas *et al.* 2014; Ababaikeli *et al.* 2016, 2018), 中国已报道的有 15 个种 1 个变型 (Wei 2020)。本属主要分布在亚热带到温带, 也有少数种延伸到热带地区 (Lumbsch 1993; Lumbsch & Aptroot 1993; Pant & Upreti 1993; Breuss & Brunnbauer 1997; Umaña & Sipman 2002), 生长在岩石、土壤、苔藓和其他地衣上。

双缘衣属地衣的主要鉴别特征为具有含黑色假薄壁组织的固有盘壁、侧丝侧生, 共生藻为共球藻 (Lumbsch 1989; Guderley & Lumbsch 1996; Guderley *et al.* 1997), 次生代谢产物主要由缩酚酸类组成 (Fernández-Brime *et al.* 2013)。这个属的地衣子囊果形态表现出显著的可变性, 子囊果呈子囊壳状 (亚球形或瓶状) 至坛状和茶渍型子囊盘状 (Lumbsch 1989)。根据地衣体和子囊盘的外部形态和内部构造, Fernández-Brime *et al.* (2013) 把双缘衣属地衣分为 3 个亚属: *Diploschistes* Norman subg. *Diploschistes*、*Diploschistes* subg. *Limborina* Fdez.-Brime, Gaya & Llimona 和 *Diploschistes* subg. *Thorstenia* Fdez.-Brime, Gaya & Llimona。

新疆气候属典型的温带大陆性干旱气候,常见种藓生双缘衣 *Diploschistes muscorum* (Scop.) R. Sant 在新疆有非常广泛的分布,准噶尔盆地、天山和昆仑山等地都能见到,双缘衣属地衣成为了新疆这样温带、干旱半干旱地区地衣群落的主要组成成分,也参与土壤结皮的形成。有研究证明双壳双缘衣 *Diploschistes diacapsis* (Ach.) Lumbsch 可形成广泛的白色地毯,在防止坡面侵蚀和植物集群方面起着重要的作用(Pintado *et al.* 2005)。

巩乃斯林场位于天山西部,具有 7.85 万 hm^2 天然林资源,海拔在 1 600–2 400 m 之间。巩乃斯林场地处天山腹地,属大陆高寒山地气候类型,冬季漫长寒冷多雪,夏季较短,雨量充沛,多东南风。这里是向西开口的喇叭口地形,自然环境拦截了到达新疆上空的大西洋和北冰洋等较湿润的大气环流,形成一定的降水量,植被生长发育繁茂,宛如是突出在整个新疆干旱戈壁荒漠大平原上的一座庞大的“绿色岛屿”。

2018–2021 年,对新疆巩乃斯林场进行地衣资源调查过程中发现了双缘衣属地衣一个新种。本文提供了新种的特征、生境的详细描述;从基因库中下载该属 13 个种、24 个 ITS 序列,并构建了系统发育树。研究结果为我国地衣的生物多样性提供科学性资料。

1 材料与方 法

1.1 材料

采自新疆天山西部巩乃斯林场的 30 余份双缘衣属地衣标本。

1.2 地衣形态解剖和化学物质的鉴定

用体式光学显微镜(SZM45)对地衣体和子囊盘外部形态进行了观察;用光学透视显微镜(Nikon DS-Fi2)对地衣体和子囊盘的内部构造进行观察。用 Nikon ECLIPSE NI-E 研究级显微镜对显微结构进行拍照。地衣体外部形态照片用 NIKON D-810 数码相机拍照。

通过显色反应法和薄层层析法(Culberson & Kristisson 1970; Culberson 1972; Orange *et al.* 2001)鉴定地衣化学成分。显色反应法常用的试剂有 K (5%–10%氢氧化钾水溶液)、C (漂白粉饱和水溶液)、KC (先使用 K,紧接着补加 C)和 P (对苯二氨乙醇溶液)等。根据呈色情况,利用检索表鉴定了地衣酸。薄层层析法中所用的溶剂系统为: C 系统(甲苯:乙酸=85:15); G 系统(甲苯:乙酸乙酯:甲酸=139:83:8)。最后对其在自然光、喷硫酸前和后 365、254 nm 处紫外光下呈现的颜色和有无荧光物质情况进行记录;并根据参照物确定样品的 Rf 值,从而确定地衣体所含物质。

1.3 分子和系统发育学分析方法

利用 Sangon Biotech 真菌基因组 DNA 抽提试剂盒[生工生物工程(上海)股份有限公司]提取 DNA,选取 rDNA-ITS 为基因标记,采用引物 ITS1F 和 ITS4 进行 PCR 扩增。PCR 反应体系: $2\times Taq$ PCR master mix 12.5 μL , 引物 ITS1F (5'-CTTGGT CATTAGAGGAAGTAA-3')和 ITS4 (5'-TCCTC CGCTTATTGATATGC-3') (10 $\mu\text{mol/L}$)各 0.5 μL , DNA 模板 2 μL , ddH₂O 9.5 μL 。PCR 反应条件: 95 $^{\circ}\text{C}$ 预变性 5 min; 10 个循环(95 $^{\circ}\text{C}$ 变性 30 s, 66 $^{\circ}\text{C}$ 退火 30 s, 72 $^{\circ}\text{C}$ 延伸 90 s); 34 个循环(95 $^{\circ}\text{C}$ 变性 30 s, 56 $^{\circ}\text{C}$ 退火 30 s, 72 $^{\circ}\text{C}$ 延伸 60 s); 72 $^{\circ}\text{C}$ 延伸 10 min。PCR 扩增产物的测序委托生工生物工程(上海)股份有限公司完成。

1.4 系统发育分析

测序成功的 ITS 序列由 DNASTAR-seqman pro 进行拼接,并将序列上传至 NCBI,获得序列号为 OP070000 和 OP070001。构建系统发育所用序列的选择参考绿盘双缘衣 ITS 序列在线 BLAST [Nucleotide BLAST: Search nucleotide databases using a nucleotide query (nih.gov)]结果与相关文献(Martín *et al.* 2003; Fernández-Brime *et al.* 2013; Abbas *et al.* 2014; Ababaikeli *et al.* 2016, 2018)在 NCBI 下载,所用 ITS 序列信息列

表 1 用于系统发育分析的物种及序列信息

Table 1 Species and sequence information used for phylogenetic analysis

物种名 Species	凭证标本号 Voucher No.	采集地 Locality	基因库序列号 GenBank No.
<i>Diploschistes ocellatus1</i>	BCC-Lich 13207	/	AF098411
<i>Diploschistes ocellatus2</i>	DUKE 144450	澳大利亚 Australia	KC167010
<i>Diploschistes cinereoacaesius1</i>	ESS 9364	委内瑞拉 Venezuela	AJ458282
<i>Diploschistes cinereoacaesius2</i>	Hb. Palice	厄瓜多尔 Ecuador	KJ542542
<i>Diploschistes wui1</i>	Abbas 20093003	中国新疆 Xinjiang, China	MG461530
<i>Diploschistes wui2</i>	Abbas 20093021	中国新疆 Xinjiang, China	MG461532
<i>Diploschistes xinjiangensis1</i>	Abbas 110821s1	中国新疆 Xinjiang, China	KJ000011
<i>Diploschistes xinjiangensis2</i>	Abbas 110821s2	中国新疆 Xinjiang, China	KJ000012
<i>Diploschistes diacapsis1</i>	DUKE 30912	西班牙 Spain	KC166978
<i>Diploschistes diacapsis2</i>	DUKE 130126	美国 USA	KC166979
<i>Diploschistes neutrophilus1</i>	BCN-Lich19357	西班牙 Spain	KC166982
<i>Diploschistes neutrophilus2</i>	BCN-Lich 19329	西班牙 Spain	KC166983
<i>Diploschistes scruposus</i>	Hb. Fdez.-Brime	西班牙 Spain	KJ542545
<i>Diploschistes gypsaceus1</i>	BCN-Lich 19324	西班牙 Spain	KC166988
<i>Diploschistes gypsaceus2</i>	BCN-Lich 19345	西班牙 Spain	KC166989
<i>Diploschistes muscorum1</i>	BCN-Lich 19344	西班牙 Spain	KC167007
<i>Diploschistes muscorum2</i>	BCN-Lich 19334	西班牙 Spain	KC167008
<i>Diploschistes viridis1</i>	20217673	中国新疆 Xinjiang, China	OP070000
<i>Diploschistes viridis2</i>	20217676	中国新疆 Xinjiang, China	OP070001
<i>Diploschistes tianshanensis1</i>	Abbas 20s1	中国新疆 Xinjiang, China	KC959951
<i>Diploschistes tianshanensis2</i>	Abbas 20s2	中国新疆 Xinjiang, China	KC959952
<i>Diploschistes diploschistoides1</i>	DUKE 144445	西班牙 Spain	KC166984
<i>Diploschistes diploschistoides2</i>	DUKE 18863	澳大利亚 Australia	KC166985
<i>Diploschistes rampoddensis1</i>	BCN-Lich 18011	西班牙 Spain	KC166993
<i>Diploschistes rampoddensis2</i>	BCN-Lich 18008	西班牙 Spain	KJ542543
<i>Thelotrema lepadinum</i>	/	/	AF546077

注：本研究自测序列加粗表示

Note: The new sequences generated in this study are indicated in boldface.

于表 1。利用 MEGA v11.0.10 对上述序列进行比对(alignment), 经过编辑修剪后利用 ModelFinder (Kalyanamoothy *et al.* 2017)的 Akaike information criterion (AIC)准则选择最佳拟合模型, 进行最大似然法(maximum likelihood, ML)分析的最适模型为 TNe+G4, 进行贝叶斯法(Bayes inference, BI)分析的最适模型为 K2P+G4。使用 IQ-TREE v1.6.12(Nguyen *et al.* 2015)在 TNe+G4 模型下进行 5 000 次超快自展(ultrafast) (Minh *et al.* 2013), 以及 Shimodaira-Hasegawa-like 近似似然比检验(Guindon *et al.* 2010)推断最大似然

系统发生, 构建 ML 树。使用 MrBayes v3.2.6 (Ronquist *et al.* 2012)在 K2P+G 模型(2 个并行运行, 1 000 000 代)下推断贝叶斯推断系统进化, 其中初始 25%的采样数据作为老化数据被丢弃 (burn in=0.25), 构建 BI 树。系统发育树的可视化与美化在 Figtree 中进行。

2 结果与分析

2.1 系统发育分析

ML 分析与 BI 分析所得的系统发育树结果一致, 最终系统发育图(图 1)。系统发育结果显

示, 13 个双缘衣物种分为了 6 个分支。双壳双缘衣 *D. diacapsis* (Ach.) Lumbsch、*D. neutrophilus* (Clauzade & Cl. Roux) Fern 和双缘衣 *D. scruposus* (Schreb.) Norman、*D. gypsaceus* (Ach.) Zahlbr 物种以较高的支持率与后验概率聚在分支 3 (Clade 3)。新疆双缘衣 *D. xinjiangensis* A. Abbas & S.Y. Guo、吴双缘衣 *D. wui* A. Abbas, S.Y. Guo & Ababaikeli 和大环形双缘衣 *D. cinereocaesius* (Sw.) Vain 3 个物种聚成分支 2 (Clade 2), 支持率为 81%, BI 后验概率为 0.99。绿盘双缘衣 *D. viridis* 与天山双缘衣 *D. tianshanensis* A. Abbas, S.Y. Guo & Ababaikeli 聚在一支, 形成姊妹群, 说明这 2 个物种有着较近的亲缘关系, 并且这 2 个

物种与藓生双缘衣 *D. muscorum* 极好地聚在分支 4 (Clade 4), 支持率为 98%, BI 后验概率为 1, 该分子系统发育的结果与形态鉴定一致, 绿盘双缘衣与天山双缘衣、藓生双缘衣有着较相似的结构特征。此外, Clade 4 还与 Clade 3 聚为分支 A (Clade A), 支持率为 57%, BI 后验概率为 0.86, 根据 Martín *et al.* (2003) 和 Ababaikeli *et al.* (2016) 的研究结果, 绿盘双缘衣可能属于 *D. scruposus* 组合。*D. diploschistoides* (Vain.) G. Salisb、斯里兰卡双缘衣 *D. rampoddensis* (Nyl.) Zahlbr 和 *D. ocellatus* (Fr.) Norman 3 个物种各自形成单系。外类群 (Outgroup) 帽贝疣孔衣 *T. lepadinum* (Ach.) Ach 位于树的基部。

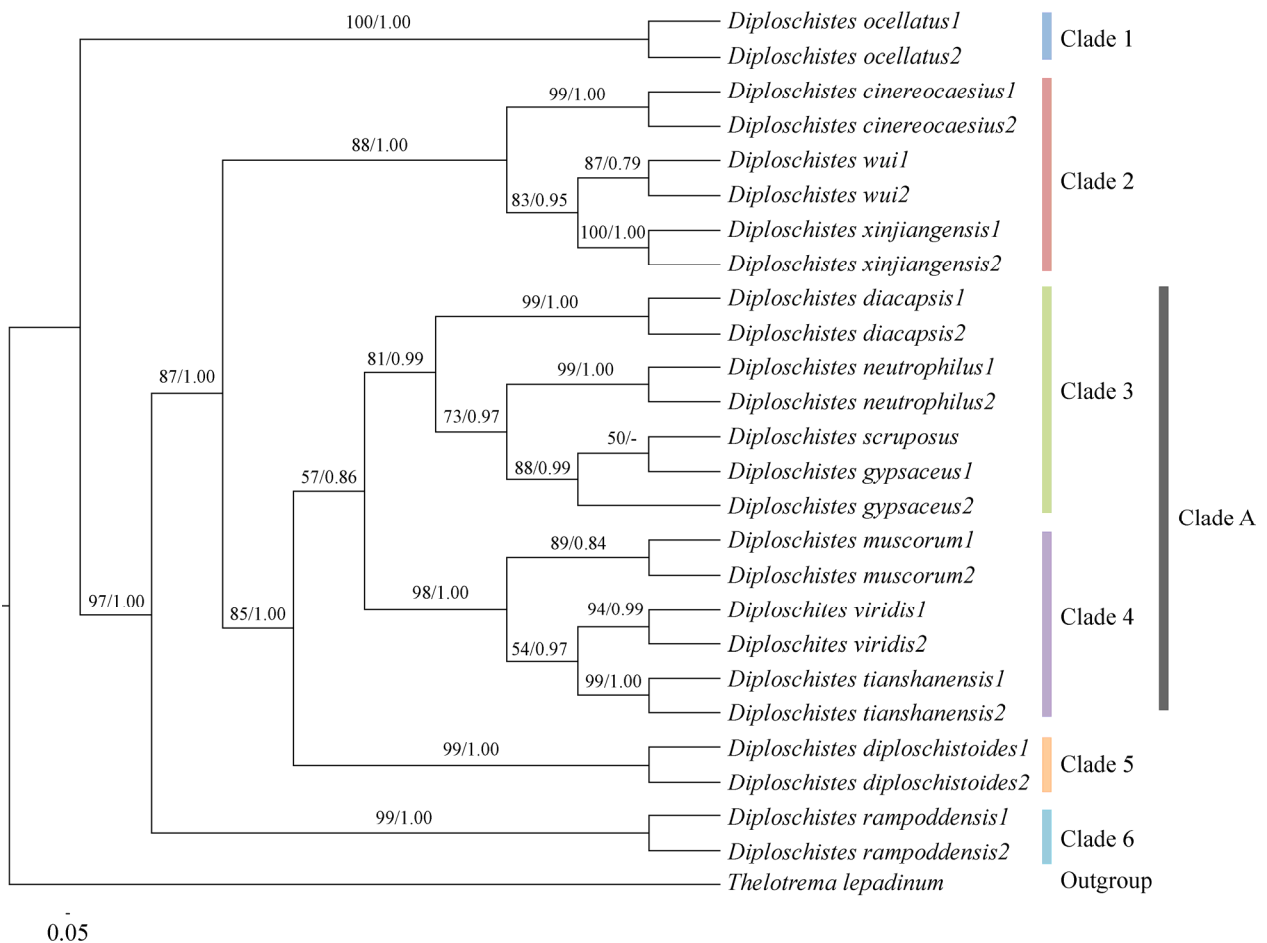


图 1 双缘衣属 ITS 序列系统发育树 仅显示支持率(ML)大于 50% 和后验概率(BI)大于 0.75 的数据
 Fig. 1 Phylogenetic tree construction of *Diploschistes* based on ITS. Maximum likelihood bootstrap value above 50% and Bayes inference posterior probability above 0.75 are shown at nodes.

2.2 分类单元

绿盘双缘衣 图 2

Diploschistes viridis R. Mamut, J.J. Fang & T. Payzulla, *sp. nov.* Fig. 2

Mycobank: MB 845080

Diagnosis: Similar to *D. tianshanensis* A. Abbas, S.Y. Guo & G. Ababaikeli, but differing in having a thick, rimosely areolate thallus, containing orsellinic acid, and saxicolous habitat.

Etymology: *viridis* referred to the green color of the lichen thallus and apothecia.

Type: China, Xinjiang, Korla, Hejing County, Mt. Tianshan, Gongnaisi forest farm, 84.534 444°E and 43.262 778°N, alt. 1 930 m, Jul. 2021, coll. Mamut R., B.T. Li, GNS 7673 (**Holotype**, XJU, GenBank OP070000, OP070001; **Isotype**, HMAS-L, HMAS-L 154766).

Description: Thallus crustose, rimosely areolate, pale grayish green, green pruina of densely distributed apothecial discs giving the thallus a greenish yellow appearance, up to 4 mm thick; margins distinct, whitish; epinecral layer 25–35 μm thick, without a well-developed cortex; photobiont trebouxoid.

Apothecia urceolate, densely distributed, 0.3–1.7 mm in diam., with an orbicular, concave disc with greenish yellow pruina. Proper exciple red brown, 60–80 μm thick. Hymenium hyaline, 140–170 μm high. Hypothecium red brown, without oil droplets, 20–40(–50) μm thick. Paraphyses simple, apices not thickened. Ascospores ellipsoid, brown, muriform, 30–38×14–17 μm. Pycnidia not observed.

Spot tests: K+ yellow, C+ and KC+ vivid red, PD–.

Secondary metabolites: Lecanoric acid, diploschistesic acid and orsellinic acid detected by TLC.

Habitat: It grows on the rocks under *Picea schrenkiana* Fisch. & C.A. Mey trees.

Additional material examined: China, Xinjiang, Korla, Hejing County, Mt. Tianshan, Gongnaisi forest farm, 84.534 444°E and 43.262 778°N, alt. 1 930 m, Jul. 2021, coll. Mamut R., B.T. Li, GNS7670, paratype; China, Xinjiang, Korla, Hejing County, Mt. Tianshan, Gongnaisi

forest farm, 84.534 444°E and 43.262 778°N, alt. 1 930 m, Jul. 2021, coll. Mamut R., B.T. Li, GNS7671, GNS7675, GNS7676, GNS7678.

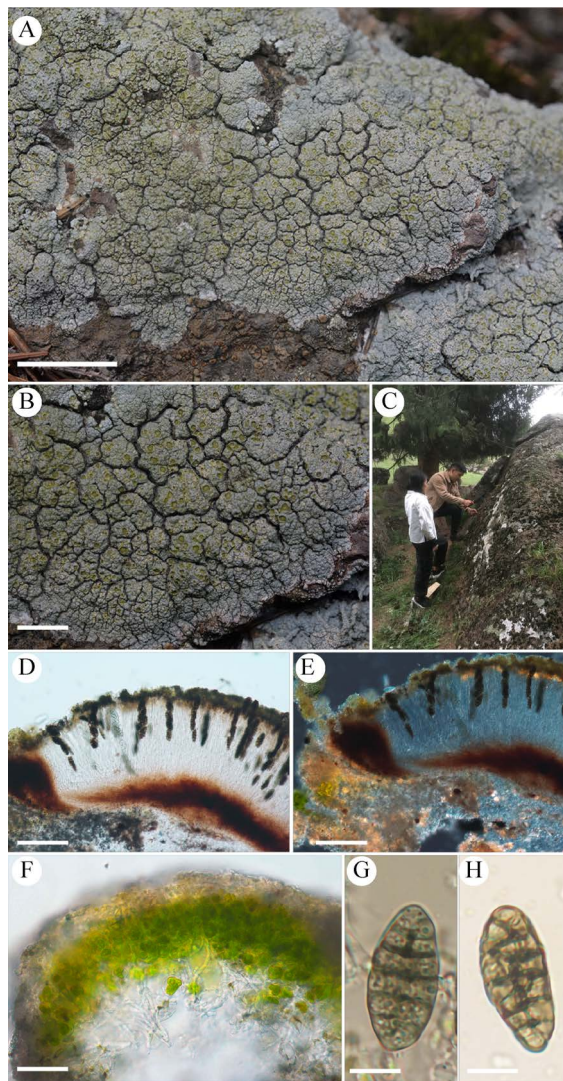


图2 绿盘双缘衣的形态和解剖结构 A: 地衣体; B: 地衣体的部分放大(示子囊盘); C: 生境; D: 子囊盘纵切; E: 子囊盘纵切(偏光镜下); F: 地衣体纵切; G, H: 子囊孢子. 比例尺: A, B=1 cm; D, E=100 μm; F=50 μm; G, H=5 μm

Fig. 2 Morphological and anatomical photos of *Diploschistes viridis* (Specimen No: GNS7673). A: Thallus; B: Magnified photo of thallus (showing the structure of apothecia); C: Habitat; D: Cross section of apothecia; E: Cross section of apothecia (in polarized light); F: Cross section of thallus; G, H: Ascospore. Scale bars: A, B=1 cm; D, E=100 μm; F=50 μm; G, H=5 μm.

Remarks: *Diploschistes viridis* is restrictedly distributed on the shady slope of Gongnaisi forest farm, with low temperature, weak evaporation, and abundant precipitation (Fig. 2C). This new species is characterized by its rimosely areolate, grayish green thallus and yellowish green apothecia. It is morphologically similar to *D. tianshanensis* having thin, continuous, muddy and uniform thallus, dark brown proper exciple, yellowish brown hypothecium, containing lecanoric acid and diploschistesic acid, without orsellinic acid, and having corticolous habitat. In *D. viridis*, thallus is rimosely areolate, forms a certain shape; proper exciple and hypothecium are red brown, containing lecanoric acid, diploschistesic acid and orsellinic acid, with a saxicolous habitat. Another similar species is *D. scruposus* (Schreb.) Norman which differs in having a brownish gray thallus, darkish apothecial disc, 100–140 μm high hymenium, and the predominantly (4–)8-spored asci. *Diploschistes viridis* has a green apothecial disc and 140–170 μm high hymenium, having always 4-spored asci. *Diploschistes viridis* is related to *D. muscorum* in having the same secondary metabolites, but the latter differs in having whitish gray, grayish or whitish pruinose, thinner thallus, being a juvenile parasite on *Cladonia* spp., and having a smaller ascospores (Lumbsch 2002). *Diploschistes wui* is also saxicolous, but it is distinguished by its thin bluish gray thallus, epruinose discs, 8-spored asci, and smaller ascospores (Ababaikeli *et al.* 2018).

Gongnaisi Forest Farm is known as a “old-growth forest”, and is located in northwest of Hejing County, Xinjiang, China. In this forest farm dead and dying trees are a favorite habitat of many epiphytic lichens, and lichen diversity on fallen trees is often higher than that on living and vital trees.

特征简介：此种与天山双缘衣相似，但是该新种地衣体龟裂状、较厚，生长基物为岩石。

词源：新种拉丁名种加词 “*viridis*” 代表该物种地衣体和子囊盘绿色。

特征：地衣体壳状，龟裂状，疣状隆起，紧

密固着于基物上，边缘清晰，白色。地衣体表面浅灰绿色，也因密集子囊盘盘面附着的粉霜颜色而呈绿黄色，厚度达 4 mm。地衣体上表面 25–35 μm 厚，藻胞层藻细胞密集，连续，共生藻为共球藻。

子囊盘坛状，圆形，子囊盘半埋生于地衣体中生长，单生，数量多，直径达 0.3–1.7 mm。盘面被浓厚的黄绿色粉霜包围。子囊盘边缘与地衣体同色，不连续，齿裂。囊层被为拟薄壁组织，红褐色，60–80 μm 厚。子实层无色，140–170 μm 高。囊层基红褐色，20–40(–50) μm 厚。侧丝单一，顶端不增厚。子囊内含 4 孢子。囊孢子椭圆形，砖壁形，褐色，30–38 \times 14–17 μm 。分生子孢子器未见。

化学反应：地衣体 K+黄色、C+紫红色，地衣体 KC+红色，PD–。

化学成分：茶渍酸，双缘衣酸，苔色酸 (TLC)。

基物：岩石。研究区域中发现，该种生长在天山云杉 *Picea schrenkiana* Fisch. & C.A. Mey. 下的岩石上。

研究标本：GNS7673 (模式标本)：东经 84.534 444°，北纬 43.262 778°，海拔 1 930 m，新疆和静县，天山西部巩乃斯林场，采集人：热衣木·马木提，李碧庭，2021 年 7 月；GNS7670、GNS7671、GNS7675、GNS7676、GNS7678：东经 84.534 444°，北纬 43.262 778°，海拔 1 930 m，新疆和静县，天山西部巩乃斯林场，采集人：热衣木·马木提，李碧庭，2021 年 7 月。

3 讨论

调查发现，绿盘双缘衣只限分布在巩乃斯林场阴坡，气温较低，蒸发较弱，为迎风坡，降水较丰富的区域(图 2C)。绿盘双缘衣与天山双缘衣 *D. tianshanensis* 在地衣体颜色、子囊盘形状和颜色、子囊孢子形状和大小方面很接近。但后

者中地衣体连续,薄,泥土形,没有固定形状,囊层被黑褐色,囊层基黄褐色,内含双缘衣酸和茶渍酸,不含苔色酸,生长在树皮上。而绿盘双缘衣地衣体较厚,具一定形状,龟裂状,囊层被和囊层基红褐色,内含双缘衣酸、茶渍酸和苔色酸,生长基物为岩石。绿盘双缘衣与双缘衣 *D. scruposus* 具有相似的龟裂状淡绿色地衣体,但双缘衣中子囊盘黑色,子实层 100–140 μm 高,子囊孢子为(4–)8 个;而绿盘双缘衣子囊盘为绿色,子实层 140–170 μm 高,子囊孢子为 4 个。绿盘双缘衣与藓生双缘衣 *D. muscorum* 有同样的次生代谢产物,但后者具有灰色和淡灰色或淡白色粉霜、较薄地衣体,未成熟时常寄生在石蕊属地衣上,并具有较小子囊孢子(Lumbsch 2002)。吴双缘衣 *D. wui* 和绿盘双缘衣都生长在岩石上,但吴双缘衣中,地衣体薄、淡蓝灰色,子囊盘盘面无粉霜,子囊孢子 8 个,孢子大小比绿盘双缘衣小(Ababaikeli *et al.* 2018)。

经考察发现,该森林内死亡的树或朽木作为栖息地的附生植物的地衣种类多,并且地衣多样性往往高于活的树木上生活的地衣种类,因此也是中国濒危地衣研究中的一个重要地区。

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