从生物化石组合特征剖析黑色页岩的沉积环境——以鄂西长阳地区寒武系牛蹄塘组为例

赵明胜[1] 王 约[2] 田景春[1] 雷灵芳[3] 杜兵盈[4]

(1.成都理工大学沉积地质研究院,四川 成都 610059;2.贵州大学资源与环境工程学院,贵州 贵阳 550025;
3.中化地质矿山总局贵州地质勘查院,贵州 贵阳 550003;4.黑龙江省区域地质调查所, 黑龙江 哈尔滨 150080)

提要:寒武系地层在鄂西地区广泛分布,湖北省长阳县天柱山以黑色炭质页岩为主要特征的寒武系牛蹄塘组下部黑色页岩中保存有丰富的高肌虫(*Sunella*)、大型双瓣壳节肢动物(*Perspicaris*)、宏体藻类、软舌螺类和可疑的海绵类((?)*Sinospongia*),同时,见有零星分布的黄铁矿。通过对生物化石古生态及保存情况的研究,认为鄂西长阳牛蹄塘组沉积早期宏体生物生活于海底表层贫氧、水体上层充氧、透光性较好的、较为平静的浅海环境,且海底处于氧化-还原界面附近。由于页(泥)岩沉积时具有较高水分,在快速沉积背景下将死亡生物躯体埋藏,伴随着沉积的不断进行,沉积水与外界水体交换量逐渐减少,加之生物腐烂产生的 H_2S 气体,形成了沉积物内部的强还原环境,有机质得以保存,最终形成黑色页(泥)岩。

关 键 词:黑色页岩;沉积环境;牛蹄塘组;寒武系;湖北长阳

中图分类号:P534.41 **文献标志码**:A **文章编号**:1000-3657(2013)05-1484-09

寒武系黑色岩系在扬子地区普遍发育,众多学者已从古生物学[1-5]、层序地层学[6-10]和地球化学[11-17]等多方面进行了高精度深入的研究工作,积累了丰富的资料,并取得了一系列重要成果。寒武系牛蹄塘组以黑色页(泥)岩为主要特征,而黑色页(泥)岩传统上被认为形成于缺氧的还原环境[18-20]。但在牛蹄塘组黑色页岩中却发现了大量的多门类化石,包括藻类、节肢动物、腔肠动物、海绵动物及疑源类等并被誉为牛蹄塘生物群[2],它们是继早寒武世梅树村期小壳动物繁盛以后又一次的生物繁盛。到目前为止,牛蹄塘组的沉积环境被认为是较深海的还原环境[3,16,18,21-27],但也有学者认为是浅海的近滨环境[28-29]。

高肌虫、大型双瓣壳节肢动物、宏体藻类以及海绵等先后被报道于鄂西及黔北等地[30-32],但通过生物组合对鄂西地区牛蹄塘沉积期沉积环境方面的研究却少有报道。本文将对来自湖北长阳天柱山(N30°28′15″,E110°57′44″)寒武系牛蹄塘组下部黑色炭质页岩中的高肌虫(*Sunella*)、大型双瓣壳节肢动物(*Perspicaris*)、宏体藻类、软舌螺、可疑的海绵类((?)*Sinospongia*)等生物组合进行古生态方面的研究(图 1-a,1-b),进而试图恢复鄂西地区牛蹄塘组下部的沉积环境。

1 区域概况

湖北长阳位于湖北省西部,属寒武纪地层分区的"中扬子区",寒武纪早期基本上继承了震旦纪晚期的沉积格局。由于震旦系灯影组沉积晚期的"惠亭运动"导致湖北中部隆起,形成鄂中古陆[33],在此基础上,绕鄂中古陆由北至南依次形成了碳酸盐潮坪、浅海陆棚、深水陆棚相区分布的早寒武世古地理格局[34-35](图 1-c)。湖北长阳牛蹄塘组剖面为一套由黑色炭质页岩为主的海相沉积地层,下伏与震旦系灯

收稿日期:2012-12-5;**改回日期**:2013-03-19

基金项目:国家自然科学基金(41162003)、贵州省科学技术基金项目(J-2010-2030)和国家科技重大专项(2011ZX05007-003-01)联合资助。

作者简介:赵明胜,男,1981 年生,博士,主要从事古生态学与沉积学的研究工作;E-mail:passion114@126.com。

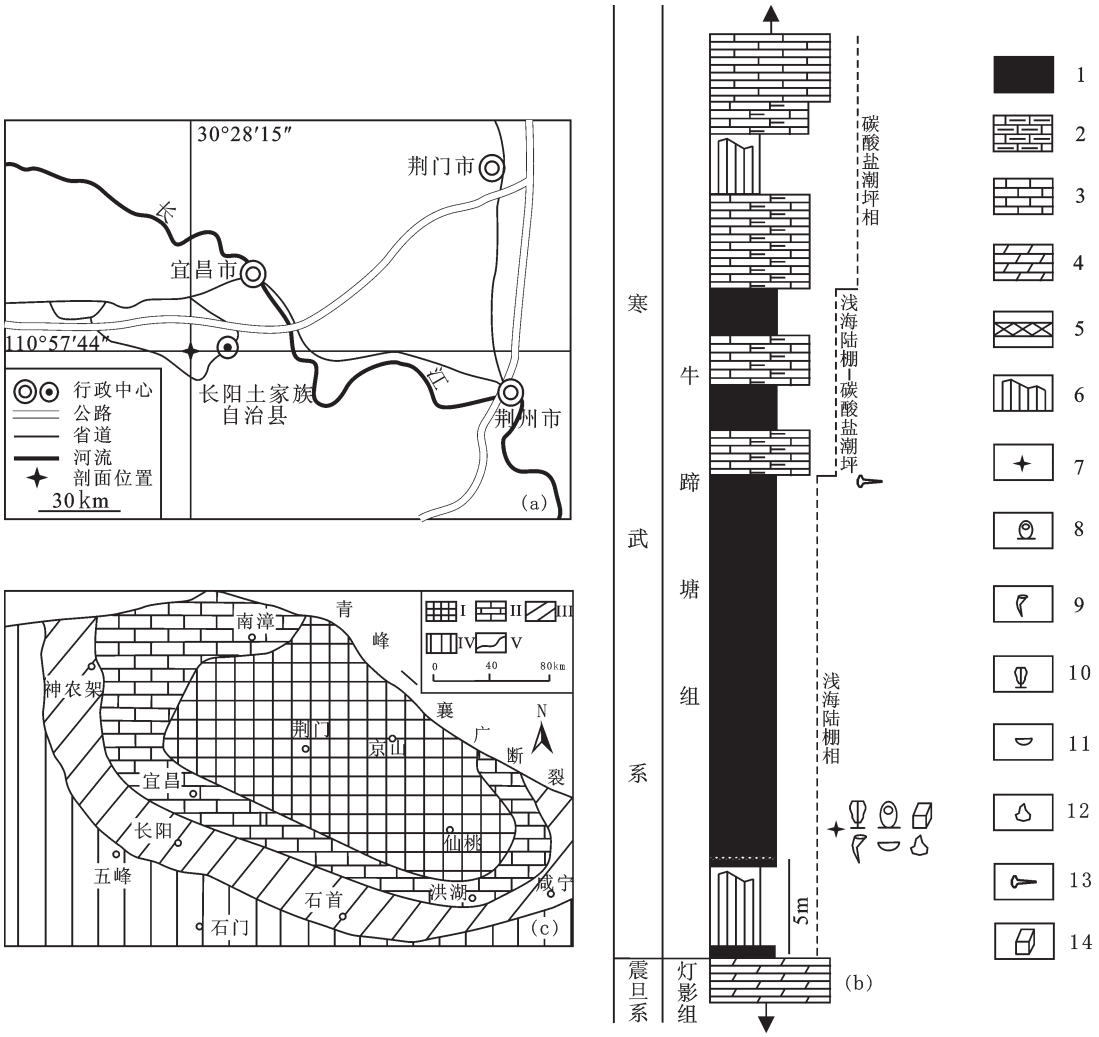

图 1 鄂西长阳天柱山牛蹄塘组宏体生物化石产出位置及层位

(a)剖面位置;(b)鄂西长阳牛蹄塘组地层柱状图;(c)寒武纪早期古地理格局(据参考文献[34-35],略有修改);I—鄂中古陆;II—碳酸盐潮坪相;III—浅水陆棚相;IV—深水陆棚相;V—相区界线;1—黑色炭质页岩(泥);2—泥质灰岩;3—石灰岩;4—白云岩;5—镍钼富集层;6—覆盖;7—化石产出层位;8—海绵;9—软舌螺;10—藻类;11—大型双瓣壳节肢动物;12—高肌虫;13—海绵骨针;14—黄铁矿

Fig.1 Location and horizons of macro-organism from Niutitang Formation at Tianzhushan, Changyang County, western Hubei

(a)Profile position; (b)Stratigraphic column of Niutitang Formation in Changyang County of western Hubei; (c)Palaeogeographic map of early Cambrian (modified after References[34-35]); I-Old land of central Hubei; II-Carbonate tidal flat facies; III-Shallow shelf facies; IV-Deep shelf facies; V-Facies boundary; 1- Black carbonaceous shale; 2-Muddy limestone; 3-Limestone; 4-Dolomite; 5-Ni-Mo-rich strata; 6-Cover; 7-Fossil horizon; 8-Sponges; 9-Hyolithes; 10-Algae; 11-Large bivalved arthropods; 12-Bradoriida; 13-Sponge spicule; 14-Pyrite

影组灰白色的白云岩相接触。向上泥质含量逐渐减少,岩性由黑色炭质页(泥)岩依次变化为黑色炭质页(泥)岩与灰色泥灰岩互层、灰色薄层状灰岩的沉积特征,其沉积相经历了由浅海陆棚相、浅海陆棚—碳酸盐潮坪相、以及碳酸盐潮坪相的变化(图 1-b),体现了海退过程中的进积型充填序列。牛蹄塘组在区域上具有南厚北薄,西厚东薄的分布特征[36]。

2 化石产出层位及保存特征

鄂西长阳牛蹄塘组下部含云母片的、产状近水平的黑色炭质页(泥)岩中(距牛蹄塘组底部 4.85~9.33 m)保存有丰富的高肌虫(*Sunella*)、大型双瓣壳节肢动物(*Perspicaris*),并伴有宏体藻类、软舌螺类和可疑的海绵类(?)*Sinospongia*)等生物化石(图 1~2)。

同时伴有零星分布的黄铁矿，并在化石层之下 2 m 左右见有厚约 10 cm 的镍钼(Ni-Mo)富集层(图 1-b)，现分别对黑色页(泥)岩中的化石保存特征介绍如下：

(1)*Sunella* Huo 最早报道于陕南梁山早寒武世筇竹寺期的地层中[37]，之后，崔智林和霍世诚[30]在湖北长阳钟鼓湾发现了 *Sunella bispinata* sp. nov. 和 *Sunella grandis similis* subsp. nov.，拓展了孙氏虫的地理分布范围。来自于鄂西长阳天柱山牛蹄塘组下部的高肌虫(宏大孙氏虫 *Sunella grandis*) 大小混杂聚集式保存于黑色页岩中，且较为完整(图 2-a~c,e,h)，双瓣壳张开与铰合线相连，似椭圆形状平铺于层面上(图 2-a,c,g,h)。前、后两端具有明显吻刺，前吻刺大于后吻刺，壳面光滑。长 0~16 mm，左单壳宽 0~9.1 mm(图 2-h)，凸度较小，壳边缘轮廓明显(图 2-a,c,e,h)。

(2)*Perspicaris* 是牛蹄塘的常见分子，多被报道产于黔北地区 [38]。*Perspicaris* 与 *Sunella* 保存于同一层面(图 2-c)，壳体呈次椭圆形单壳保存(图 2-c,d,h)，壳长 7~14 mm，壳宽为 6.7~9.5 mm，壳边缘明显。

(3)多细胞宏体藻类早在震旦系陡山沱组沉积期就已出现，并且可以明显地分出固着器和营养体两部分[39]。保存于湖北长阳天柱山寒武系牛蹄塘组下部的宏体藻类以炭质薄膜方式平铺于层面上 (图 2-f,i,j)，见叶状体和固着器两部分保存(图 2-f)。叶状体侧向弯曲(图 2-f,j)，无分枝，呈带状、透镜状或椭圆形(图 2-f,i,j)，部分叶状体保存完整(图 2-i,j)，保存长度为 5.6~11.7 mm，叶宽为 2.5~7.5 mm，叶状体边缘明显，呈黑色，边缘内部为灰黑色(图 2-f)。藻柄部分保存完整或不完整(图 2-f,i,j)，柄短，长 0.6~4.5 mm，粗 0.7~1.7 mm。固着器(图 2-f,j)明显加粗，短小，较藻柄宽，约 2.0~2.5 mm。

(4)可疑的海绵动物(?)*Sinospongia* 化石呈柱状保存(图 2-k)，表面灰黑—灰色—灰白相间(图 2-k)，保存长度为 1.2 cm，宽度约为 0.6 cm，顺长度方向可略见膨大—缩小，表面见有环形线纹(图 2-k)。

(5)软舌螺是牛蹄塘组地层中的常见分子，天柱山剖面的软舌螺化石壳体小，侧向弯曲，锥管状，顶端尖细，见有生长环或光滑表面，保存壳长为 9~14 mm，壳口呈圆形，壳口端直径为 3.1~3.8 mm(图 2-l,m)。

3 讨 论

宏体藻类通常伴随着大量动物化石出现，两者之间具有密切的关系[4]。宏体藻类在陡山沱晚期已发育有明显的固着器[40-43]，来自于鄂西天柱山地区牛蹄塘组下部黑色页岩中的宏体藻类化石保存有完好的藻柄和固着器(图 2-f,i,j)，表明为营底栖固着生活。宏体藻类依赖固着器固着于沉积物表面或表层，叶状体在水体中由藻柄支撑呈直立的半漂浮状态，竖立于海底。植物的生命活动依赖阳光进行。因此，天柱山地区可能处于透光带较好的浅海地区。CO_2 在早寒武世的浓度是今天的 20 倍[44]，并通过大气-海洋层面的交换溶入海洋中。使竖立于海底的、呈半漂浮状的宏体藻类大幅度地提高了光合作用的效率，增加了水体中的含氧量[41,45-46]，改善了水体环境，促进水体中生物的生长、发育和繁殖。

海绵动物 *Sinospongia* 具有“拟根”状的固着器，被认为是底栖固着生活于沉积物表面[46]，为底栖滤食性动物[32]。Marek 和 Yochelson[47]曾认为软舌螺为浮游生物，而钱逸和肖立功[48]通过对软舌螺内部的结构研究，认为是以底栖缓慢活动为主的软体动物类。Rhoad and Morse[49]根据氧气在水中的溶解度将古氧相划分为充氧、贫氧和缺氧三个类别，并认为充氧环境适宜多种生物的生存，贫氧环境生物的分异度明显降低，而在缺氧的状态下生物几乎不能存活。牛蹄塘组下部黑色页岩中产出有营底栖固着生活的可疑海绵动物 (?)*Sinospongia* 和底栖缓慢活动的软舌螺，而生活于沉积物表面的宏体生物的生长与繁殖需要一定量的氧气[43]，这意味着牛蹄塘沉积早期的海底具有氧存在。然而，牛蹄塘组下部的宏体化石数量较少，且属种相对较为单调，表明湖北长阳牛蹄塘沉积早期的海水底部可能处于贫氧的环境。

高肌虫 *Sunella* 由于其具有较长的绞合线(大于壳长)、壳层薄、而且壳面光滑(图 2-a,b,e,g)，因而崔智林和霍世诚[30]认为系营浮游生活并具快速游泳能力的生物。*Perspicaris* 也被认为是游泳型生活，生活于水体上层 [38]。牛蹄塘组下部丰富的营浮游生物 *Sunella* 和 *Perspicaris* 的存在，表明牛蹄塘沉积早期的水体表层中处于相对充氧的状态。另外，牛蹄塘组下部的 *Sunella* 在数量上占有优势地位，且其聚集式保存的双瓣壳以绞合线相连(图 2-a,b,e,g)，大小混杂(图 2-c,h)，说明在死亡保存的过程中未受到强烈的水动力作用，为弱水动力的近原地埋藏，表明牛蹄塘沉积早期天柱山地区曾处于相对平静的沉积环境。在化石层之下 2 m 左右发育有厚约 10 cm 的镍

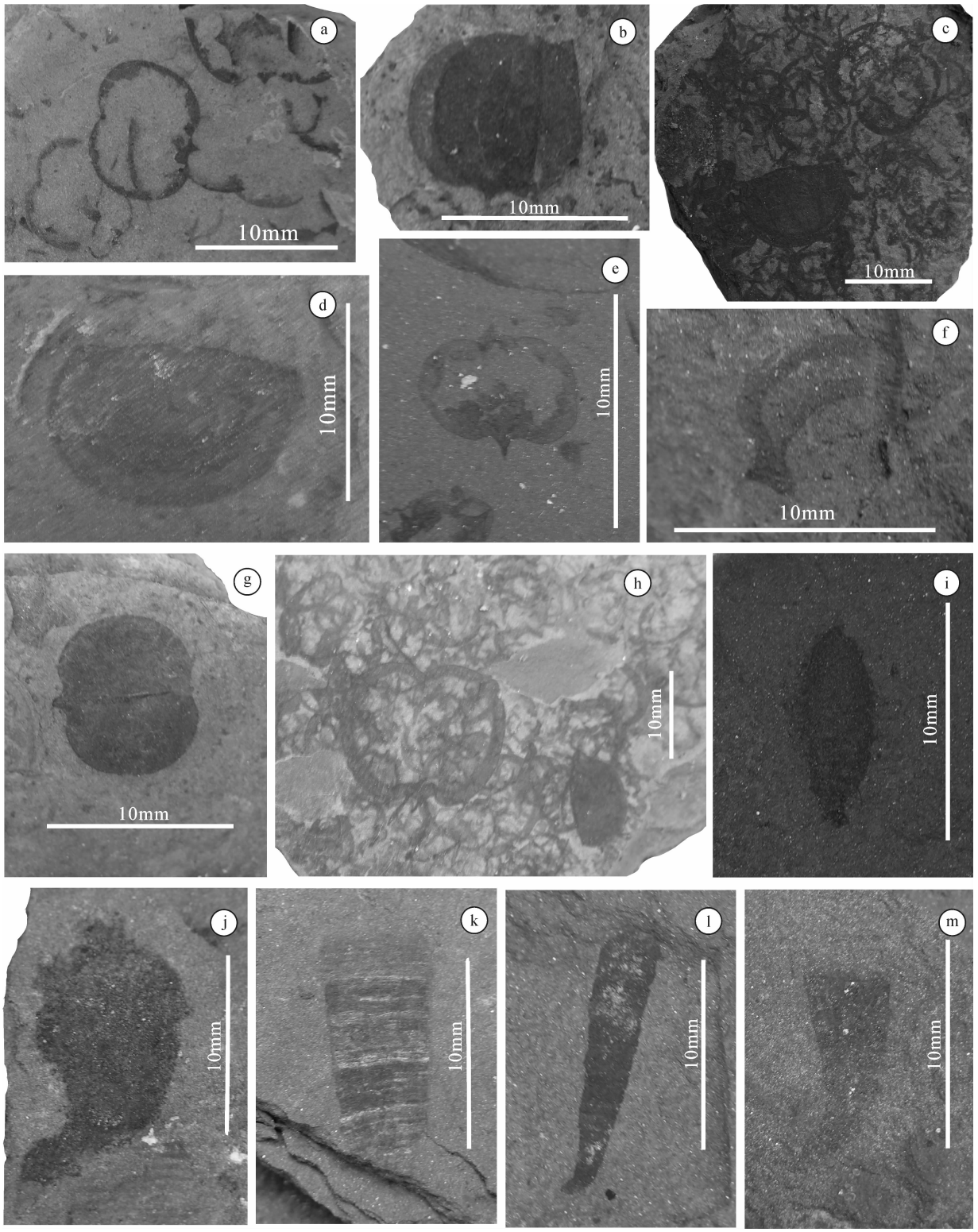

图 2 湖北长阳天柱山牛蹄塘组下部化石

a,b,e,g—宏大孙氏虫(*Sunella grandis*);c,h—宏大孙氏虫(*Sunella grandis*)与锐虾虫未定种(*Perspicaris* ? sp.)共生,大小混杂;d—锐虾虫未定种(*Perspicaris* ? sp.);f,i,j—宏体藻类(属、种未定);k—可疑的海绵((?)*Sinospongia* sp.);l,m—软舌螺(属、种未定)

Fig.2 Fossils from lower Niutitang Formation in Tianzhushan section, Changyang Country, Hubei Province

a,b,e,g–*Sunella grandis*;c,h–*Sunella grandis* and *Perspicaris* ? sp. commensalism, mixed sizes;d–*Perspicaris* ? sp.;f,i,j–Macroscopic algal, gen. et sp. indet.;k–(?)*Sinospongia* sp.;l,m–Hyolithes, gen. et sp. indet

钼富集层(图 1-b),镍钼富集层普遍被认为是热液喷发形成[26,50-57],热水可为生物的繁殖提供丰富的营养物质。综上所述,鄂西长阳地区保存于牛蹄塘组下部黑色页(泥)岩中的宏体生物生活于贫氧-充氧、透光性较好的、相对平静的浅海环境,并且海底可能处于氧化-还原界面附近。

另外,鄂西天柱山牛蹄塘组见有零星分散黄铁矿的黑色页岩普遍被认为系缺氧的、还原环境下的沉积[3,16,18-27],而与牛蹄塘沉积期繁盛的生物似乎相矛盾。笔者做如下解释:页(泥)岩沉积时含有较高水分,甚至于有人认为其含水量在 80%以上[40,58],沉积颗粒之间由沉积水充填,使其呈软质-粥状的沉积物[40,43,46]。而在此基底之上生活有固着生长的宏体藻类以及底栖的海绵类(?)*Sinospongia* 和软舌螺,特别是两侧对称的软体动物软舌螺类的存在,表明其海底表面为有氧的环境。另外,生活于富氧水体表层的浮游类 *Sunella* 和 *Perspicaris* 等生物死亡后,沉降于沉积物的表面。处于贫氧状态的水体底部,生物遗体不易腐烂。同时,随着沉积物的不断沉积,具有较高水分的泥(页)岩可将死亡生物快速掩埋[40,58-59],软质-粥状沉积物的颗粒之间沉积水与海水之间的交换量减少,而有利于生物死亡后躯体的完整保存。另外、生物遗体在厌氧菌的腐蚀作用下,分解产生硫化氢(H_2S)气体,形成沉积物内部的强还原环境,促进了有机质的保存[43,47],最终形成黑色页(泥)岩。

4 结 论

鄂西天柱山牛蹄塘组下部黑色页岩中保存有丰富的高肌虫 *Sunella*、大型双瓣壳节肢动物 *Perspicaris*、并伴有宏体藻类、软舌螺类和可疑的海绵类(?)*Sinospongia* 等生物化石。其中宏体藻类通过固着器与软质-粥状基底相接触,呈半漂浮状态竖立于海底,通过光合作用,大幅度增加了海水中的含氧量,因而推测湖北长阳地区在牛蹄塘组沉积早期处于透光带较好的、相对浅海的环境。另外,可疑的海绵(?)*Sinospongia* 和软舌螺底栖表生生物的存在,且保存数量较少,属种较为单调,意味着海底处于较为贫氧的状态。而生活于水体上层的营浮游生活 *Perspicaris* 以及两瓣壳相连的 *Sunella* 存在,代表了弱水动力的、充氧的沉积环境。因而推测鄂西长阳牛蹄塘组沉积早期处于贫氧-充氧、透光性较好的、相对平静的浅海环境,并且海底可能处于氧化-还原界面附近。另外,化石层之下的 Ni-Mo 富集层被认为是热水沉积成因,为生物的大量繁殖提供了营养物质。大量繁盛的生物,促进了有机质的生产,并在沉积物内部的强还原环境中得以保存,最终形成黑色页(泥)岩。

致谢:审稿专家提出了十分宝贵的建议,在此表示衷心的感谢!参加野外工作的还有中国地质大学(北京)的杨艳飞同学。

参考文献(References):

[1] 舒德干. 贵州福泉牛蹄塘组最古老的双壳类化石[J]. 古生物学报, 1986, 25(2):219-222.
Shu Degan. Notes on the oldest fossil bivalves from the Niutitang Formation of Fuquan, Guizhou [J]. Acta Palaeontologica Sinica, 1986, 25(2):219-222(in Chinese with English abstract).

[2] 赵元龙, Steiner M, 杨瑞东, 等. 贵州遵义下寒武统牛蹄塘组早期后生生物群的发现及重要意义[J]. 古生物学报, 1999, 38(增刊):132-144.
Zhao Yuanlong, Steiner M, Yang Ruidong, et al. Discovery and significance of the early metazoan biotas from the Lower Cambrian Niutitang Formation Zunyi, Guizhou, China [J]. Acta Palaeontologica Sinica, 1999, 38(Supp.):132-144(in Chinese with English abstract).

[3] 杨瑞东, 张位华, 姜立君, 等. 澄江生物群分子在贵州遵义牛蹄塘组发现[J]. 地质学报, 2003, 77(2):145-150.
Yang Ruidong, Zhang Weihua, Jiang Lijun, et al. Members of the Chengjiang biota from the Lower Cambrian Niutitang Formation, Zunyi County, Guizhou Province, China[J]. Acta Geologica Sinica, 2003, 77(2):145-150(in Chinese with English abstract).

[4] 杨瑞东, 赵元龙, 郭庆军. 贵州早寒武世早期黑色页岩中藻类及其环境意义[J]. 古生物学报, 1999, 38(增刊):145-154.
Yang Ruidong, Zhao Yuanlong, Guo Qingjun. Algae and acritarchs and their palaeooceanographic significance from the Early Cambrian black shale in Guizhou,China [J]. Acta Palaeontologica Sinica, 1999, 38(Supp.):145-154(in Chinese with English abstract).

[5] 杨瑞东, 朱立军, 高慧, 等. 贵州遵义松林寒武系底部热液喷口及与喷口相关生物群特征[J]. 地质论评, 2005, 51(5):481-490.
Yang Ruidong, Zhu Lijun, Gao Hui, et al. A study on characteristics of the hydrothermal vent and relating biota at the Cambrian bottom in Songlin, Zunyi County, Guizhou Province[J]. Geological Review, 2005, 51(5):481-490(in Chinese with English abstract).

[6] 梅冥相, 马永生, 邓军, 等. 上扬子区下古生界层序地层格架的初步研究[J]. 现代地质, 2005, 19(4):551-562.
Mei Mingxiang, Ma Yongsheng, Deng Jun, et al. Sequence-stratigraphic framework for the early Palaeozoic of the upper-Yangtze region [J]. Geoscience, 2005, 19 (4):551-562 (in Chinese with English abstract).

[7] 梅冥相, 马永生, 张海, 等. 上扬子区寒武系的层序地层格架—寒

武纪生物多样性事件形成背景的思考 [J]. 地层学杂志, 2007, 31(1):68-78.
Mei Mingxiang, Ma Yongsheng, Zhang Hai, et al. Sequence-stratigraphic frameworks for the Cambrian of the upper-Yangtze region:Ponder on the sequence stratigraphic background of the Cambrian biological diversity events [J]. Journal of Stratigraphy, 2007, 31(1):68-78(in Chinese with English abstract).

[8] 梅冥相, 张海, 孟晓庆, 等. 上扬子区下寒武统的层序地层划分和层序地层格架的建立[J]. 中国地质, 2006, 33(6):1292-1304.
Mei Mingxiang, Zhang Hai, Meng Xiaoqing, et al. Sequence stratigraphic division and framework of the Lower Cambrian in the Upper Yangtze region [J]. Geology in China, 2006, 33 (6):1292-1304(in Chinese with English abstract).

[9] 赵亮东, 郭荣涛. 贵州东南部下寒武统层序地层格架 [J]. 中国地质, 2011, 38(3):277-285.
Zhao Liangdong, Guo Rongtao. Lower Cambrian sequence-stratigraphic framework of southeastern Guizhou Province [J]. Geology in China, 2011, 38 (3):277-285 (in Chinese with English abstract).

[10] 梁超, 姜在兴, 郭岭, 等. 黔北地区下寒武统黑色页岩沉积特征及页岩气意义[J]. 断块油气田, 2012, 19(1):22-26.
Liang Chao, Jiang Zaixing, Guo Ling, et al. Sedimentary characteristics and shale gas significance of Lower Cambrian black shale in Qianbei area[J]. Fault-Block Oil & Gas Field, 2012, 19(1):22-26(in Chinese with English abstract).

[11] 吴朝东, 储著银. 黑色页岩微量元素形态分析及地质意义[J]. 矿物岩石地球化学通报, 2001, 20(1):14-19.
Wu Chaodong, Chu Zhuyin. Sequential extraction of trace elements and the geological significance of fractions in black shales, west Hunan and east Guizhou[J]. Bulletin of Mineralogy Petrology and Geochemistry, 2001, 20 (1):14-19 (in Chinese with English abstract).

[12] 吴朝东, 杨承运, 陈其英. 湘西黑色岩系地球化学特征和成因意义[J]. 岩石矿物学杂志 , 1999, 18(1):26-38.
Wu Chaodong, Yang Chengyun, Chen Qiying. The origin and geochemical characteristics of Upper Sinain-Lower Cambrian black shales in western Hunan[J]. Acta Petrologica et Mineralogica, 1999, 18(1):26-38(in Chinese with English abstract).

[13] 杨剑, 易发成, 侯兰杰. 黔北黑色岩系的岩石地球化学特征和成因[J]. 矿物学报, 2004, (3):285-289.
Yang Jian, Yi Facheng, Hou Lanjie. Genesis and petrogeochemistry characteristics of Lower Cambrian black shales in northern Guizhou [J]. Acta Mineralogica Sinica, 2004, (3):285-289(in Chinese with English abstract).

[14] 杨剑, 易发成, 刘涛, 等. 黔北黑色岩系稀土元素地球化学特征及成因意义[J]. 地质科学, 2005, 40(1):84-94.
Yang Jian, Yi Facheng, Liu Tao, et al. REE geochemical characters of the Lower Cambrian black shale series in northern Guizhou and their original significance [J]. Chinese Journal of Geology, 2005, 40(1):84-94(in Chinese with English abstract).

[15] 易发成 杨剑 侯兰杰, 等. 黔北黑色岩系的铂族元素地球化学特征及成因探讨[J]. 地质科学, 2004, 39(3):367-374.
Yi Facheng, Yang Jian, Hou Lanjie, et al. Origin and geochemistry of platinum group elements of Lower Cambrian black shale series in north Guizhou [J]. Chinese Journal of Geology, 2004, 39(3):367-374(in Chinese with English abstract).

[16] 袁宏, 肖加飞, 何熙琦, 等. 黔北牛蹄塘组的地球化学特征及形成环境[J]. 贵州地质, 2007, 24(1):55-63.
Yuan Hong, Xiao Jiafei, He Xiqi, et al. Geochemical characteristics and formation environment of the Niutitang Formation in the north Guizhou [J]. Guizhou Geology, 2007, 24 (1):55-63 (in Chinese with English abstract).

[17] 皮道会, 刘丛强, 邓海琳, 等. 贵州遵义牛蹄塘组黑色岩系有机质的稀土元素地球化学研究. 矿物学报, 2008, (3):303-309.
Pi Daohui, Liu Congqiang, Deng Hailin, et al. REE geochemistry of organic matter from black shales of the Niutitang Formation, Zunyi, Guizhou Province [J]. Acta Mineralogica Sinica, 2008, (3):303-309(in Chinese with English abstract).

[18] 肖加飞, 胡瑞忠, 宋谢炎, 等. 贵州早寒武世的缺氧事件沉积[J]. 矿产与地质, 2006, 20(4/5):366-373.
Xiao Jiafei, Hu Ruizhong, Song Xieyan, et al. Early Cambrian anoxic event sedimentation in Guizhou Province [J]. Mineral Resources and Geology, 2006, 20(4/5):366-373(in Chinese with English abstract).

[19] 齐文同. 事件地层学[M]. 北京:地质出版社, 1990:57-58.
Qi Wentong. Event Stratigraphy[M]. Beijing:Geological Publishing House, 1990:57-58(in Chinese).

[20] 雷加锦, 李任伟, Tobschall H J, 等. 扬子地台南缘早寒武世黑色岩系中形态硫特征及成因意义 [J]. 中国科学 (D 辑), 2000, 30(6):592-601.
Lei Jiajin, Li Renwei, Tobschall H J, et al. The origin and sulphur characteristics of Early Cambrian blackshales on the south fringe of Yangtze platform[J]. Science in China(Series D), 2000, 30(6):592-601(in Chinese).

[21] 周志毅, 袁金良, 张正华, 等. 贵州及其邻近地区寒武纪生物地理分区[J]. 地层学杂志, 1979, 3(2):258-271.
Zhou Zhiyi, Yuan Jinliang, Zhang Zhenghua, et al. Guizhou and its neighboring region Cambrian biological geographical division[J]. Acta Stratigraphica Sinica, 1979, 3(2):258-271(in Chinese).

[22] 张长俊, 陶晓风, 刘跃. 湖北省早寒武世水井沱期构造岩相带与矿产的关系[J]. 成都理工大学学报, 1982, 2:33-44.
Zhang Changjun, Tao Xiaofeng, Liu Yue. The relation between tectonic lithofacies and minerals in the Shuijingtuo period of Early Cambrian Hubei Province [J]. Journal of Chengdu University of Technology, 1982, 2:33-44(in Chinese).

[23] 蒲心纯, 周浩达, 王熙林, 等. 中国南方寒武纪岩相古地理与成矿作用[M]. 北京:地质出版社, 1993:1-191.
Pu Xinchun, Zhou Haoda, Wang Xilin, et al. China Southern Cambrian Lithofacies Paleogeographic and Mineralization [M]. Beijing:Geological Publishing House, 1993:1-191(in Chinese).

[24] Lambert I B, Walter M R, Zang Wenlong, et al. Paleoenvironment and carbon isotope stratigraphy of upper Proterozoic carbonates of the Yangtze Platform[J]. Nature, 1987, 325:140-142.

[25] 李任伟, 卢家烂, 张淑坤, 等. 震旦纪和早寒武世黑色页岩有机碳同位素组成[J]. 中国科学(D 辑), 1999, 29(4):351-357.
Li Renwei, Lu Jialan, Zhang Shukun, et al. Organic carbon isotopes of the Sinian and Early Cambrian black shales on Yangtze Platform, China[J]. Science in China (series D), 1999, 42(6):595-603.

[26] Steiner M, Wallis E, Erdtmann B D, et al. Submarine-hydrothermal exhalative ore layers in black shales from south China and associated fossils——insights into a Lower Cambrian facies and bioevolution [J]. Paleogeogr. Paleoclimatal. Paleoecol, 2001, 169: 165-191.

[27] 王琛, 林丽, 李德亮, 等. 黔西纳雍地区下寒武统牛蹄塘组黑色岩系生物标志物的特征[J]. 地质通报, 2011, 30(1):106-111.
Wang Chen, Lin Li, Li Deliang, et al. Characteristics of biomarkers of the black rock series of Lower Cambrian Niutitang Formation in the Nayong area, western Guizhou, China [J]. Geological Bulletin of China, 2011, 30(1):106-111(in Chinese with English abstract).

[28] Kˇríbek B. Organic geochemistry and petrology of barren and Mo-Ni-PGE mineralized marine black shales of the Lower Cambrian Niutitang Formation (South China) [J]. International Journal of Coal Geology, 2007, 72(3/4):240-256.

[29] 朱建明, Johnson T M, 罗泰义, 等. 贵州遵义牛蹄塘组黑色岩系的硒同位素变化及其环境指示初探 [J]. 岩石矿物学杂志, 2008, 27(4):361-365.
Zhu Jianming, Johnson T M, Luo Taiyi. A tentative discussion on the variation of selenium isotopes in black shale of Niutitang Formation, Zunyi, Guizhou Province, and its implications for depositional environment [J]. Acta Petrologica et Mineralogica, 2008, 27(4):361-365(in Chinese with English abstract).

[30] 崔智林, 霍世诚. 鄂西下寒武统甲壳类化石新发现[J]. 古生物学报, 1990, 29(3):321-327.
Cui Zhilin, Huo Shicheng. New discoveries of Lower Cambrian crustacean fossils from western Hubei [J]. Acta Palaeontologica Sinica, 1990, 29(3):321-327(in Chinese with English abstract).

[31] 杨兴莲, 朱茂炎, 赵元龙, 等. 贵州寒武纪海绵动物化石组合特征[J]. 微体古生物学报, 2005, 22(3):295-303.
Yang Xinglian, Zhu Maoyan, Zhao Yuanlong, et al. Cambrian sponge assemblages from Guizhou [J]. Acta Micropalaeontologica Sinica, 2005, 22(3):295-303(in Chinese with English abstract).

[32] 杨兴莲, 赵元龙, 朱茂炎. 贵州下寒武统牛蹄塘生物群中海绵新材料[J]. 古生物学报, 2005, 44(3):454-463.
Yang Xinglian, Zhao Yuanlong, Zhu Maoyan. New sponges from the Lower Cambrian of Guizhou [J]. Acta Palaeontologica Sinica, 2005, 44(3):454-463(in Chinese with English abstract).

[33] 湖北省地质矿产局. 湖北省区域地质志[M]. 北京:地质出版社, 1990:4-87.
Bureau of geology and mineral resources of Hubei Province. Hubei Province Regional Geological Volunteers [M]. Beijing:Geological Publishing House, 1990:44-87(in Chinese).

[34] 李忠雄, 陆永潮, 王剑, 等. 中扬子地区晚震旦世—早寒武世沉积特征及岩相古地理[J]. 古地理学报, 2004, 6(2):151-162.
Li Zhongxiong, Lu Yongchao, Wang Jian, et al. Sedimentary characteristics and lithofacies palaeogeography of the Late Sinian and Early Cambrian in middle Yangtze region [J]. Journal of Palaeogeography, 2004, 6 (2):151-162 (in Chinese with English abstract).

[35] 陈家林, 田文, 牟宗玉, 等. 鄂西地区牛蹄塘组钼钒矿地质特征及找矿远景探讨[J]. 华南地质与矿产, 2010, 1:40-47.
Chen Jialin, Tian Wen, Mu Zongyu, et al. Geological feature and prospecting potential of Molybdenum-Vanadium deposits in Niutitang Formation,western Hubei Province [J]. Geology and Mineral Resources of South China, 2010, 1:40-47 (in Chinese with English abstract).

[36] 湖北省地质矿产局. 全国地层多重划分对比研究——湖北省岩石地层[M]. 武汉:中国地质大学出版社, 1996:57-139.
Bureau of Geology and Mineral Resources of Hubei Province. The National Multiple Stratigraphic Division and Research——Hubei Province Rock Formation [M]. Wuhan:China University of Geosciences Press, 1996:57-139(in Chinese).

[37] 霍世诚. 陕西、云南早寒武世古介形虫 (续志)[J]. 古生物学报, 1965, 13(2):291-303.
Huo Shicheng. Early Cambrian ancient aluta in Shaanxi and Yunnan (Renewal volunteers)[J]. Acta Palaeontologica Sinica, 1965, 13(2):291-303(in Chinese with English abstract).

[38] 崔滔, 杨兴莲, 赵元龙. 贵州遵义松林寒武纪早期牛蹄塘生物群埋藏学特征初探[J]. 古生物学报, 2010, 49(2):210-219.
Cui Tao, Yang Xinglian, Zhao Yuanlong. Preliminary taphonomic analyses of the Early Cambrian Niutitang biota near Songlin,Zunyi, Guizhou[J]. Acta Palaeontologica Sinica, 2010, 49(2):210-219(in Chinese with English abstract).

[39] 郭俊锋, 李勇, 舒德干. 湖北三峡地区纽芬兰统岩家河组的宏体藻类化石[J]. 古生物学报, 2010, 49(3):336-342.
Guo Junfeng, Li Yong, Shu Degan. Fossil macroscopic algae from the Yanjiahe Formation, Terreneuvian of the Three Gorges area, south China[J]. Acta Palaeontologica Sinica, 2010, 49(3):336-342 (in Chinese with English abstract).

[40] 王约, 王训练. 黔东北新元古代陡山沱期宏体藻类的固着器特征及其沉积环境意义[J]. 微体古生物学报, 2006, 23 (2):154-164.
Wang Yue, Wang Xunlian. The holdfasts of macroalgae in the Neoproterozoic Doushantuo Formation in northeastern Guizhou Province and their environmental significance [J]. Acta Micropalaeontologica Sinica, 2006, 23 (2):154-164 (in Chinese with English abstract).

[41] 王约, 王训练, 黄禹铭. 黔东北伊迪卡拉纪陡山沱组的宏体藻类[J]. 地球科学——中国地质大学学报, 2007, 32(6):828-844.
Wang Yue, Wang Xunlian, Huang Yuming. Macroscopic algae from the Ediacaran Doushantuo Formation in northeast Guizhou, south

China [J]. Earth Science——Journal of China University of Geosciences, 2007, 32(6):828-844(in Chinese with English abstract).

[42] 王约, 赵明胜, 杨艳飞, 等. 华南陡山沱期晚期宏体生物生态系统的出现及其意义[J]. 古地理学报, 2009, 11(6):640-650.
Wang Yue, Zhao Mingsheng, Yang Yanfei, et al. Emergence of marco-organismal ecosystem of the late Doushantuoian in South China and its significance [J]. Journal of Palaeogeography, 2009, 11(6):640-650(in Chinese with English abstract).

[43] 王约, 雷灵芳, 陈洪德, 等. 扬子板块伊迪卡拉(震旦)纪多细胞生物的发展与烃源岩的形成 [J]. 沉积与特提斯地质, 2010, 30(3):30-38.
Wang Yue, Lei Lingfang, Chen Hongde, et al. Development of the Ediacaran (Sinian) multicellular organisms and formation of the source rocks in the Yangtze area [J]. Sedimentary Geology and Tethyan Geology, 2010, 30(3):30-38(in Chinese with English abstract).

[44] Crowley T J, Berner R A. Palaeoclimate:Enhanced CO_2 and climate change[J]. Science, 2001, 292(5518):870.

[45] 陈孟莪, 萧宗正, 袁训来. 晚震旦世的特种生物群落——庙河生物群新知[J]. 古生物学报, 1994, 33(4):391-403.
Chen Menge, Xiao Zongzheng, Yuan Xunlai. A new assemblage of megafossils——Miaohe biota from upper Sinian Doushantuo Formation, Yangtze gorges [J]. Acta Palaeontologica Sinica, 1994, 33(4):391-403(in Chinese with English abstract).

[46] 王约, 何明华, 喻美艺, 等. 黔东北震旦纪陡山沱组晚期庙河型生物群的生态特征及埋藏环境初探[J]. 古地理学报, 2005, 7(3):327-335.
Wang Yue, He Minghua, Yu Meiyi, et al. Preliminary discussion on ecological characteristics and buried environments of Miaohe-type biota during the late Doushantuoian of Sinian in northeastern Guizhou Province [J]. Journal of Palaeog Eography, 2005, 7(3):327-335(in Chinese with English abstract).

[47] Marek L, Yochelson E L. Aspects of the biology of Hyolitha (Mollusca) [J]. Lethaia, 1976, 9(1):65-82.

[48] 钱逸, 肖立功. 软舌螺[M]. 北京:科学出版社, 1995:1-277.
Qian Yi, Xiao Ligong. Hyolithes[M]. Beijing:Science Press, 1995:1-277(in Chinese).

[49] Rhoads D C, Morse J W. Evolutionary and environmental significance of oxygen deficient marine basins [J]. Lethaia, 1971, 4:413-428.

[50] 李胜荣, 高振敏. 湘黔地区牛蹄塘组黑色岩系稀土特征——兼论海相热水沉积岩稀土模式[J]. 矿物学报, 1995, 15(2):225-229.
Li Shengrong, Gao Zhenmin. REE characteristics of black rock series of the Lower Cambrian Niutitang Formation in Hunan-Guizhou Provinces, China, with a discussion on the REE patterns in marine hydrothermal sediments [J]. Acta Mineralogica Sinica, 1995, 15(2):225-229(in Chinese with English abstract).

[51] 李胜荣, 肖启云, 申俊峰, 等. 湘黔下寒武统铂族元素来源与矿化年龄的 Re-Os 同位素制约[J]. 中国科学(D 辑), 2002, 32(7):568-575.
Li Shengrong, Xiao Qiyun, Shen Junfeng, et al. PGE source and mineralization age Re-Os isotope restriction in the Lower Cambrian from Hunan and Guizhou[J]. Science in China(Series D), 2002, 32(7):568-575(in Chinese).

[52] 李有禹. 湘西北镍钼多金属喷气沉积矿床的地球化学特征[J]. 地球化学, 1997, 26(3):89-95.
Li Youyu. Geochemistry of Ni-Mo polymetallic exhalation sediment ore deposit in northwestern Hunan[J]. Geochimica, 1997, 26(3):89-95(in Chinese with English abstract).

[53] 罗泰义, 宁兴贤, 罗远良, 等. 贵州遵义早寒武黑色岩系底部的 Se 的超常富集[J]. 矿物学报, 2005, 25(3):276-282.
Luo Taiyi, Ning Xinxian, Luo Yuanliang, et al. Super-enrichment of Se in the bottom black shales Lower Cambrian at Zunyi, Guizhou Province, China [J]. Acta Mineralogica Sinica, 2005, 25(3):276-282(in Chinese with English abstract).

[54] 罗泰义, 张欢, 李晓彪, 等. 遵义牛蹄塘组黑色岩系中多元素富集层的主要矿化特征[J]. 矿物学报, 2003, 23(4):296-302.
Luo Taiyi, Zhang Huan, Li Xiaobiao, et al. Mineralization characteristics of the multi-element-rich strata in the Niutitang Formation black shale series, Zunyi, Guizhou, China [J]. 2003, 23(4):296-302(in Chinese with English abstract).

[55] Jiang Shaoyong, Chen Yongquan, Ling Hongfei, et al. Trace and rare earth element geochemistry and Pb-Pb dating of black shales and in tercalated Ni-Mo-PGE-Au sulfide ores in Lower Cambrian strata, Yangtze platform, south China[J]. Miner Deposita, 2006, 41(5):453-467.

[56] Jiang Shaoyong, Yang Jinghong, Ling Hongfei, et al. Re-Os isotopes and PGE geochemistry of black shales and inter calated Ni-Mo polymetallic sulfide bed from the Lower Cambrian Niutitang Formation, south China [J]. Progress in Natural Science, 2003, 13(10):788-794.

[57] 陈益平, 潘家永, 胡凯, 等. 贵州遵义镍-钼富集层中独居石的发现及成因意义[J]. 岩石矿物学杂志, 2007, 26(4):340-343.
Chen Yiping, Pan Jiayong, Hu Kai, et al. Discovery of monazite in the Ni-Mo sulfide layer of Zunyi, Guizhou Province, and its genetic significance [J]. Acta Petrologica et Mineralogica, 2007, 26(4):340-343(in Chinese with English abstract).

[58] 张正华, 沈建伟, 龚显英, 等. 贵州台江中寒武世凯里动物群保存环境初探[J]. 古生物学报, 1996, 35(5):607-622.
Zhang Zhenghua, Shen Jianwei, Gong Xianyin, et al. A preliminary discussion on preservation condition of Kaili Fauna, Middle Cambrian, Taijiang, Guizhou [J]. Acta Palaeontologica Sinica, 1996, 35(5):607-622(in Chinese with English abstract).

[59] 邓义楠, 王 约, 陈洪德, 等. 黔北桐梓五峰组观音桥段双壳类和腹足类的生态意义[J]. 地层学杂志, 34(3):328-333.
Deng Yinan, Wang Yue, Chen Hongde, et al. Bivalves and gastropods from the Ordovician Guanyinqiao Member of the Wufeng Formation in Tongzi, Guizhou, south China, and their ecological significance[J]. Journal of Stratigraphy, 34(3):328-333(in Chinese with English abstract).

A sedimentary environment analysis of black shales based on fossil assemblage characteristics: A case study of Cambrian Niutitang Formation in Changyang area, western Hubei

ZHAO Ming-sheng[1], WANG Yue[2], TIAN Jing-chun[1], LEI Ling-fang[3], DU Bing-ying[4]

(1. *Institute of Sedimentology, Chengdu University of Technology, Chengdu* 610059, *Sichuan, China;* 2. *School of Resources and Environments, Guizhou University, Guiyang* 550025, *Guizhou, China;* 3. *Guizhou Institute of Geological Survey, China Chemical Geology and Mine Bureau, Guiyang* 550003, *Guizhou, China;* 4. *Institute of Regional Geological Survey of Heilongjiang Province, Harbin* 150080, *Heilongjiang, China*)

Abstract: The Cambrian strata are widely distributed in western Hubei area. Abundant *Sunella* (Bradoriida), *Perspicaris* (large bivalved arthropods), macroscopic algal, hyolithes and (?)*Sinospongia* (Suspicious sponges) have been found in the lower black carbonaceous shale of the Cambrian Niutitang Formation from Tianzhu area of Changyang County, Hubei Province. In addition, scattered pyrite is seen in black shale. Based on a detailed study of palaeoecology and the characteristics of fossils preservation, the authors have reached the conclusion that, during the early sedimentary stage of Niutitang Formation in Changyang County of western Hubei Province, macro-organism lived in an environment of shallow water which was suboxic at the bottom, oxic in the upper part characterized by good light transmission and relative calmness, and that the sea bottom surface was located nearby the redox interface. Besides, under the background of rapid deposition, large amounts of water and dead biological-bodies were embedded in shale, the amount of water exchange between the depositional water and the external water decreased gradually, and H_2S gas was generated by rotton organism in the process of deposition, forming a strong reduction environment in sediments, so that organic matter could be preserved, which eventually formed black shale.

Key words: black shale; sedimentary environment; Niutitang Formation; Cambrian; Changyang County of Hubei Province

---

About the first author: ZHAO Ming-sheng, male, born in 1981, doctor, mainly engages in the study of paleoecology and sedimentology; E-mail: passion114@126.com.