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下扬子地区奥陶纪宁国—胡乐期岩相古地理及页岩 油气远景分析

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摘要:【研究目的】下扬子地区奥陶纪宁国—胡乐期发育 2 套黑色页岩, 具备一定的页岩油气资源潜力, 但其平面分布形态及厚度依然不清, 因此开展岩相古地理研究对于探讨其页岩油气远景具有重大意义。【研究方法】本文对下扬子地区宁国—胡乐期沉积地层开展了详细的野外地质调查及室内测试分析, 通过岩性、沉积构造和古生物化石组合等方面的研究来开展岩相古地理学研究。【研究结果】共识别出碳酸盐岩缓坡相和碎屑岩陆棚相 2 种沉积相类型。碳酸盐岩缓坡相主要发育于下扬子地区的北部和西部, 依据岩性及生物特征进一步划分为浅水缓坡和深水缓坡, 浅水缓坡岩性以生物亮晶灰岩、泥晶灰岩、泥质灰岩为主, 深水缓坡主要发育瘤状灰岩、龟裂纹生物灰岩和页岩; 碎屑岩陆棚相则主要发育于下扬子地区的南部和东部, 可进一步细分为浅水陆棚和深水陆棚, 二者的主要差异为深水陆棚中硅质含量增高、生物群变化及有机质含量增高。【结论】通过编图首次重建了下扬子地区宁国—胡乐早期—胡乐晚期 3 个时期的岩相古地理, 皖南的绩溪—旌德—宁国—一线胡乐组页岩厚度大、有机质丰度高可成为下一步古生界页岩油气勘探的重点远景区。

关键词:页岩气; 黑色页岩; 宁国—胡乐期; 岩相古地理; 页岩油气远景; 油气勘查工程; 下扬子地区

创新点:首次重塑了下扬子地区奥陶纪宁国—胡乐期 3 期岩相古地理, 确定了皖南的绩溪—旌德—宁国地区为奥陶系页岩油气勘探的重点远景区。

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Lithofacies paleogeography and shale oil and gas prospective analysis of the Ordovician Ningguo–Hule period in the Lower Yangtze region

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Abstract: This paper is the result of oil and gas exploration engineering.

[Objective] Two sets of black shales occurred in the Ordovician Ningguo–Hule period in the Lower Yangzi region have some potential for shale oil and gas resources. However, the planar extension and vertical thickness of the shale are still unclear. Accordingly, petrographic paleogeographic studies are of greatest significance for exploring their hydrocarbon resource prospects. **[Methods]** A detailed field geological survey and test analysis were carried out regarding the Ningguo–Huleian sedimentary strata in the Lower Yangtze area. Based on the study of lithology, sedimentary structure and paleontological fossil assemblages, we carry out the research of lithofacies paleogeography. **[Results]** Two types of sedimentary facies are identified: carbonate gentle slope facies and clastic shelf facies. Carbonate gentle slope facies mainly existed in the northern and western parts of the Lower Yangtze region, and can be further divided into shallow water gentle slope and deep water gentle slope according to lithologic and biological characteristics. The shallow water gentle slope is dominated by biological spangled limestone, mud–crystal limestone and argillaceous limestone, while the deep water gentle slope is dominated by nodular limestone, turtle crack biolimestone and shale. The clastic shelf facies mainly developed in the southern and eastern parts of the Lower Yangzi region, and can be further divided into shallow– and deep–water shelves. The main differences between the two subfacies are the increased silica content, biota variation and higher organic matter content in the deep–water shelf. **[Conclusions]** The study reconstructed three stages of the paleogeographic pattern during the Ningguo–Hule Period initially. The Hule Formation of Jixi–Jingde–Ningguo in Southern Anhui province has large shale thickness and high organic matter abundance, which can become a critical prospective zone of Paleozoic shale oil and gas.

Key words: shale gas; black shale; Ningguo–Hule period; lithofacies paleogeography; shale oil and gas prospect; oil and gas exploration engineering; Lower Yangtze region

Highlights: We reconstructed the three stages of the paleogeographic pattern during the Ordovician Ningguo–Huleian period in the Lower Yangtze region initially. The Jixi–Jingde–Ningguo area in Southern Anhui Province was considered as a critical prospective zone of Ordovician shale oil and gas.

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1 引言

奥陶纪全球发生了一系列重要的生物事件和地质事件,其中包括奥陶纪生物大辐射事件(Great Ordovician Biodiversification Event)和全球海平面变化造成的台地淹没事件(Sepkoski, 1979, 1981; 刘宝珺等, 1993; 李志明等, 1997; 詹仁斌等, 2013)。这两大事件为该时期整个中国南方带来了丰富的有机质(胡华蕊等, 2019; 郑民等, 2019)。近几年来随着南方页岩气基础地质调查工程的逐步深入,下扬子地区在奥陶纪中晚期广泛发育的宁国—胡乐

组黑色页岩成为下古生界页岩气勘探中新发现的一套重要的烃源岩(郭念发等, 1998; 龚建明等, 2017; Bao et al., 2018; Chen et al., 2018; Zhai et al., 2018a, b; 方朝刚等, 2020)。有关下扬子地区这套烃源岩的文章或报道很少,研究程度低,该时代对应的岩相古地理研究资料匮乏,且前人资料多数针对个别岩相、个别时期、分省、分区研究的,导致研究区页岩分布情况和展布形态不清(穆恩之等, 1980; 江西省区域地层表编写组, 1980; 李积金, 1983; 安徽省地质矿产局区域地质调查队编著, 1989a, b; 郭养和, 1992; 赖才根等, 1993; 杜建波等, 2007; 王传

尚等,2009;宫维莉,2010;Wang et al., 2018)。以上因素严重制约了该套烃源岩的油气资源评价,亟需开展该时期整个下扬子地区的岩相古地理研究,分析沉积盆地性质以及盆内沉积充填序列和沉积式样。本文以“构造控盆、盆地控相、相控油气基本地质条件”这一理论为指导(牟传龙等,2014),结合沉积学、岩石学、构造学和古生物学等理论方法,在收集资料和野外剖面、钻孔岩心观察的基础上,研究下扬子地区宁国—胡乐期沉积相及古地理,并结合页岩气评价的基本参数,探讨该区域的页岩油气远景。

2 区域构造背景

下扬子地区是指扬子准地台在长江下游地段内的范围,东与环太平洋构造带相邻,西和西北分别以郯庐断裂带和苏鲁造山带与华北板块为界,西南到江西九江与中扬子地区相连,南和东南以江绍断裂与华夏板块为界,跨越苏、浙、皖、赣、沪四省一市,面积约 $22.5 \times 10^4 \text{ km}^2$ (图1)。

早古生代期间的下扬子海盆具有被动大陆边缘的特点,地壳稳定性相对较差,海盆的发展伴随着较强的伸展断陷,先后在滁州和浙皖赣交界地区形成了2个裂陷槽(滁州陆缘裂陷盆地和江南裂陷盆地),盆内主要发育黑色岩系,盆地外围及裂陷残留块体为浅海台地,两者呈雁行排列,构成了本区早古生代坳、隆相间的沉积格局(许正龙和翟爱军,2002;王改卫,2009),在早寒武世和中奥陶世共发育两期大的海侵事件,形成了两套优质烃源岩(荷塘组/宁国—胡乐组)。隆凹格局一直持续到中奥陶世,伴随着加里东运动前幕的到来,扬子板块和华夏板块挤压碰撞作用加剧,华夏古陆呈现继续隆升、强力的西张态势。它的隆升导致扬子板块边缘出现挠曲,使得研究区在晚奥陶世—早志留世成为前陆盆地^①(赖才根等,1993;吴跃东和钟华明,2002;李海滨,2013)。

3 地层划分对比

下扬子地区奥陶系出露较好,分布范围广,依据地层分布情况和岩性特征,且结合区域地质资料将研究区划分为下扬子地层区和江南地层区。笔者依据中国标准奥陶系三统七阶的划分方案,以中国科学院南京地质古生物研究所的《中国海相地层

岩石地层单元对比表》资料为主体,结合各个省的区域地质志,建立了下扬子地区奥陶系的划分对比格架(图2)。下扬子地层区西北侧以郯庐断裂带为界,南达东至一石台—宣城—金坛一线以北,西以团风—麻城断裂与中扬子地层区相接,东以常州—湖州—萧山一线与江南地层区分开。

下扬子地层区主要发育一套碳酸盐岩沉积,宁国—胡乐期对应地层有大湾组、紫台组、牯牛潭组、油榨岭组、庙坡组和大田坝组。大湾组(宁国期)岩性以浅灰色厚层龟裂纹瘤状灰岩或泥质灰岩为主,含腕足类和笔石化石;宿松—安庆—和县一带略有差异,下部发育灰色页岩夹灰岩透镜体,上部以薄层灰岩为主,富含头足类,厚度一般几米至十几米;与大湾组同期的紫台组,在东至一青阳一线相变为紫红色瘤状灰岩。牯牛潭组(胡乐早期)岩性以生物碎屑灰岩、泥质灰岩为主,宿松—安庆—铜陵一带相变为灰黄色中厚层灰岩、泥质灰岩、龟裂纹灰岩;与其同时期沉积的油榨林组,岩性以黄绿色粉砂质页岩夹瘤状泥灰岩为主,含三叶虫。胡乐晚期在下扬子地层分区有两种不同类型的沉积特征,在和县—含山—庐江—宿松一带命名为庙坡组,岩性为页岩夹灰岩,灰岩成分由下向上增多,动物群为笔石、头足类、介形虫等,沉积厚度相对较薄,多数在1~3 m;同期发育的大田坝组分布范围广泛,无为一带为灰黄色中厚层状泥质瘤状灰岩,东至、青阳、泾县一带相变为灰红、紫红色灰岩、泥质灰岩,富含头足类、三叶虫,厚度1.9~9.7 m,而南京—昆山—上海一线则发育中厚层生屑灰岩为主。

江南地层区位于九江—东至—石台—泾县—宣城—金坛一线以南,江绍结合带一线以北,包括江西中北部、安徽南部和浙江的广大地区,为一北东向南西的狭长地带,主要沉积一套细碎屑岩沉积。分区内奥陶系发育齐全、化石丰富,为中国奥陶系江南型的标准地区。宁国—胡乐期在该区发育宁国组、胡乐组。宁国组主体岩性为灰绿、灰黄、黄绿色页岩夹粉砂质页岩,富含笔石,浙江江山—常山地区页岩中普遍夹灰岩透镜体。胡乐组依据岩性和生物特征,划分为上下两段,下段发育灰黑色硅质页岩、硅质条带页岩和炭质硅质页岩;上段发育硅质页岩夹泥质砂质页岩,本组富含笔石。宁国组—胡乐组界线一般以黑色炭硅质页岩的出现

为标志。

4 沉积相类型及特征

根据下扬子地区奥陶纪宁国—胡乐期近 60 个剖面 and 最新页岩气钻孔的资料,开展岩石学、古生物学、地球化学、沉积构造和沉积层序的分析,结合前人的研究成果,将该区宁国—胡乐期划分为碳酸

盐岩缓坡相、碎屑岩陆棚相 2 种沉积相类型。

4.1 碳酸盐岩缓坡相

碳酸盐岩缓坡依据岩性、沉积构造和生物特征进一步划分为浅水缓坡和深水缓坡。

浅水缓坡在宁国—胡乐期都有发育,主要分布在碳酸盐岩沉积区的江苏地区和余杭—上海地区,该沉积相化石类型单调,岩性以骨屑亮晶灰岩、泥

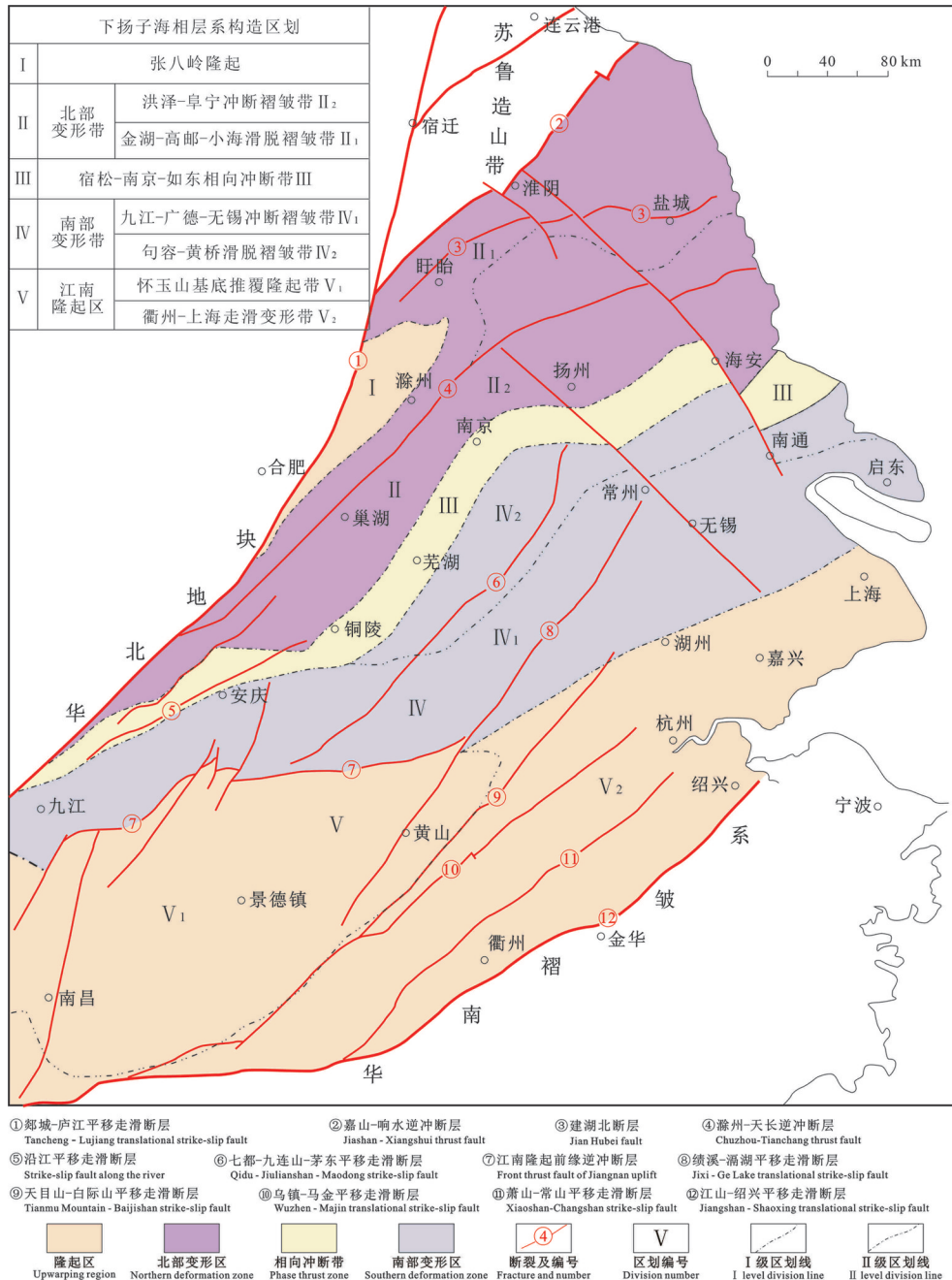


图1 下扬子海相构造纲要图(据罗开平等, 2016 修改)

Fig.1 Outline map of marine facies structure in the Lower Yangtze Region (modified from Luo Kaiping et al., 2016)

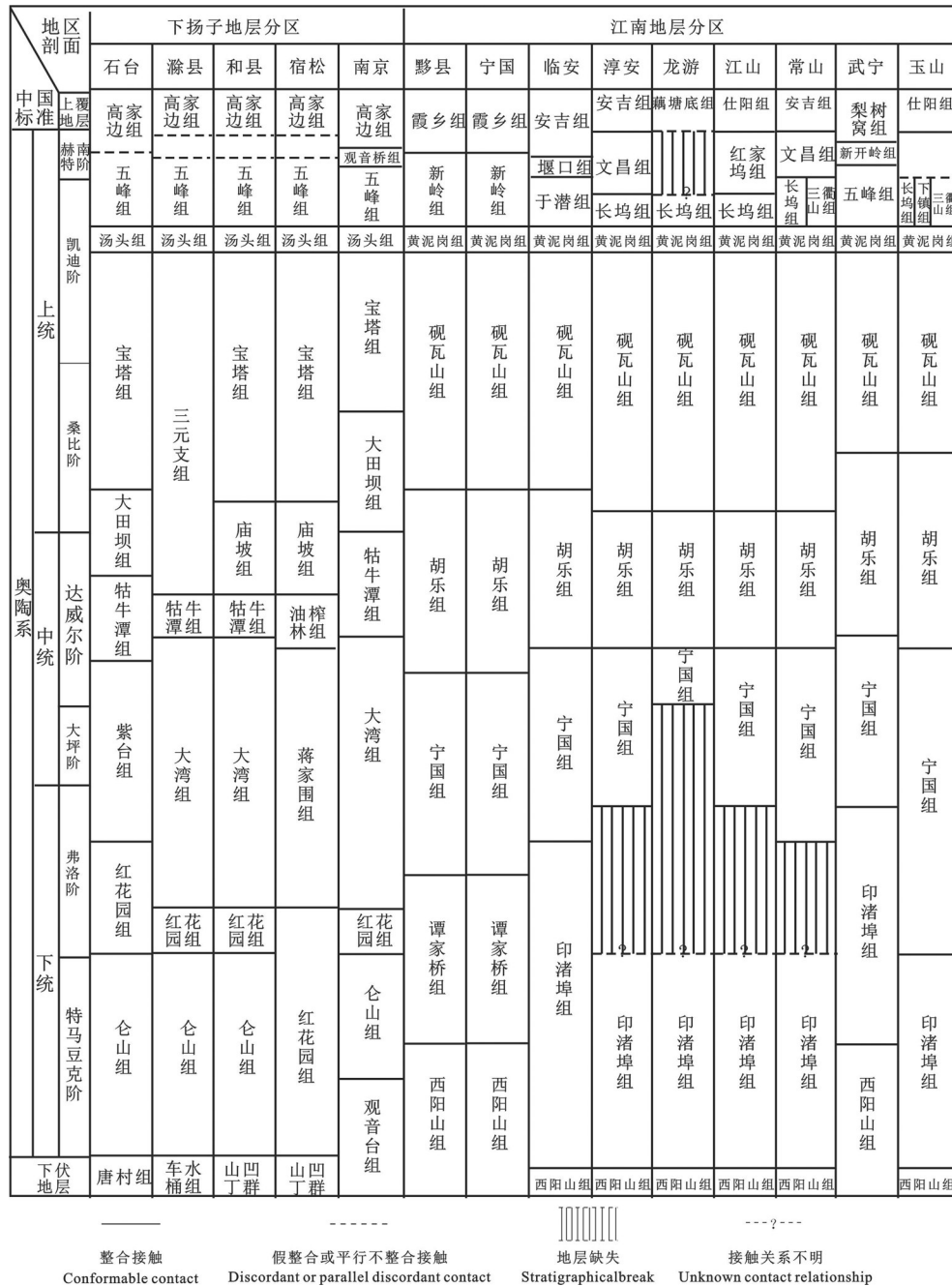


图2 下扬子地区中上奥陶统划分及其对比[⊙]

Fig.2 The division and contrast of the Middle and Upper Ordovician in the Lower Yangtze Region[⊙]

晶灰岩、泥质灰岩为主(图3a)。骨屑亮晶灰岩颗粒径以毫米级为主,颗粒成分来自生物三叶虫、头足类、腕足类、棘皮类和介形虫,含量一般不超过50%,层理不发育,有时可见少许波状层理、透镜状层理和生物构造等。生物稀少且单调,未发现任何暖水型造礁生物的踪迹(图4a),这与王建坡等(2012)所认为的扬子区这一时期没有生物礁发育

的假说,水体偏深且偏凉一致。

深水缓坡主要发育于宁国期和胡乐晚期,皖中和皖南地区都有分布,岩性以大湾组和庙坡组的瘤状灰岩、龟裂纹生物灰岩和页岩为主(图3b)。瘤状灰岩的形成环境要求沉积速率低、生物搅动作用弱和适度的底流活动的条件(图4b)。沉积速率低或者中断时,可以在沉积物—海平面附近造成充分的

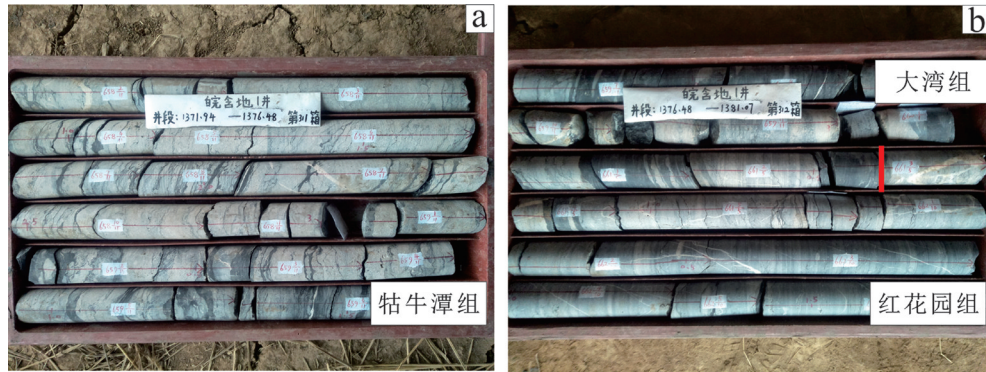


图3 WHD1井大湾组—牯牛潭组岩性特征照片

a—灰色含泥生屑灰岩夹薄层钙质页岩, WHD1井牯牛潭组; b—灰黑色泥岩夹薄层泥质灰岩, WHD1井大湾组

Fig.3 Lithologic characteristics of the Dawan Formation—Guniutan Formation in WHD1 well

a—Gray mud-bearing calcareous limestone interlaced with thin calcareous shale, Guyutan Formation, Well WHD1; b—Gray-black mudstone with thin layer of marl limestone, Dawan Formation, Well WHD1

时间进行物质再分配,产生分凝作用和胶缩作用,有利于瘤体或结合的形成。龟裂纹生物灰岩呈灰至粉红色,瘤体形状不规则、大小不均,且排列无规则性,瘤体被不规则网纹状分割和围绕,构成网纹状构造,瘤体岩性主要为生物屑微晶灰岩和含生物屑微晶灰岩(黄乐清等, 2019)。生物屑大部分由头足类、海百合茎、三叶虫、腕足类组成。网纹条带很细,毫米级,成分主要为黏土质。

4.2 碎屑岩陆棚相

陆棚相指在正常浪基面以下向外海与大陆斜坡相接的广阔的浅海沉积地区。依据位置和古水深可细分为浅水陆棚和深水陆棚。

浅水陆棚水深约几十米至一百米,沉积物主要由灰黑色薄—中薄层状粉砂质页岩、页岩组成(图5a, b),局部夹炭质页岩和硅质或灰岩条带(图5c),海底底流不发育。层理以微波状层理、微细水平层理为特征,见于皖南、浙江和江西的宁国组(图6a)。

深水陆棚主要发育于胡乐期,该沉积相主要指的是在陆架基底上受加里东运动早期构造挤压形成的陆棚凹陷沉积区,水深大致100~200 m,在皖中、皖南和浙江、江西地区均有此沉积。胡乐组在本区的厚度为几十米至一百多米,沉积物大部呈灰黑至黑色,水平层理和微波状层理发育,主要成分为黏土矿物、硅质和少量的有机质和黄铁矿(图5d, e, f),生物群以漂浮的笔石动物群和浮游生物放射虫为主(图6b)。

5 岩相古地理

下扬子地区宁国—胡乐期共发育2次海侵,胡

乐早期短时间内发生过海水相对变浅的过程。宁国期碳酸盐岩沉积区整个海平面相对加深,之前红花园期镶边型碳酸盐台地被淹没,转化为碳酸盐岩缓坡相龟裂纹灰岩和瘤状灰岩,沉积速率减慢,黏土质含量显著增加;碎屑岩沉积区则转化为细碎屑岩沉积(图7)。本次古地理采用优势相分析方法,主要探讨宁国—胡乐组黑色页岩的沉积特征和盆地内沉积充填序列。为了更清楚地研究下扬子地区中晚奥陶世碳酸盐岩与黑色页岩岩性转换阶段的沉积相及古地理特征,选取了宁国期、胡乐早期、胡乐晚期3个不同的黑色页岩发育期来编制相应的古地理图。

5.1 宁国期

中奥陶世是整个华南构造—沉积转型的重要时期。虽然古地理格局并未发生重大改变,但是构造环境已经由伸展状态转化为挤压状态。下扬子地区沉积相带展布总体上呈北东—南西走向,分为碳酸盐岩缓坡区和细碎屑岩陆棚区。受宁国早期海平面上升作用影响,原来碳酸盐岩区的浅水台地区转化为碳酸盐岩缓斜坡沉积,碎屑岩沉积区亦相对加深,由之前的灰岩、钙质泥岩、粉砂质泥岩为主台地—浅水陆棚沉积逐渐向页岩、硅质页岩为主的深水陆棚过渡(图8)。

碳酸盐岩沉积区滁县一带出露的上欧冲剖面 and 三元支北剖面,岩性为浅灰色龟裂纹含泥质结晶灰岩,含腕足和笔石化石,厚度9~20 m;另据陈旭等(1988)资料,宁镇山脉地区的大湾组下部为骨屑含泥质泥晶—微晶灰岩,含海绿石和磷质骨屑;大湾组

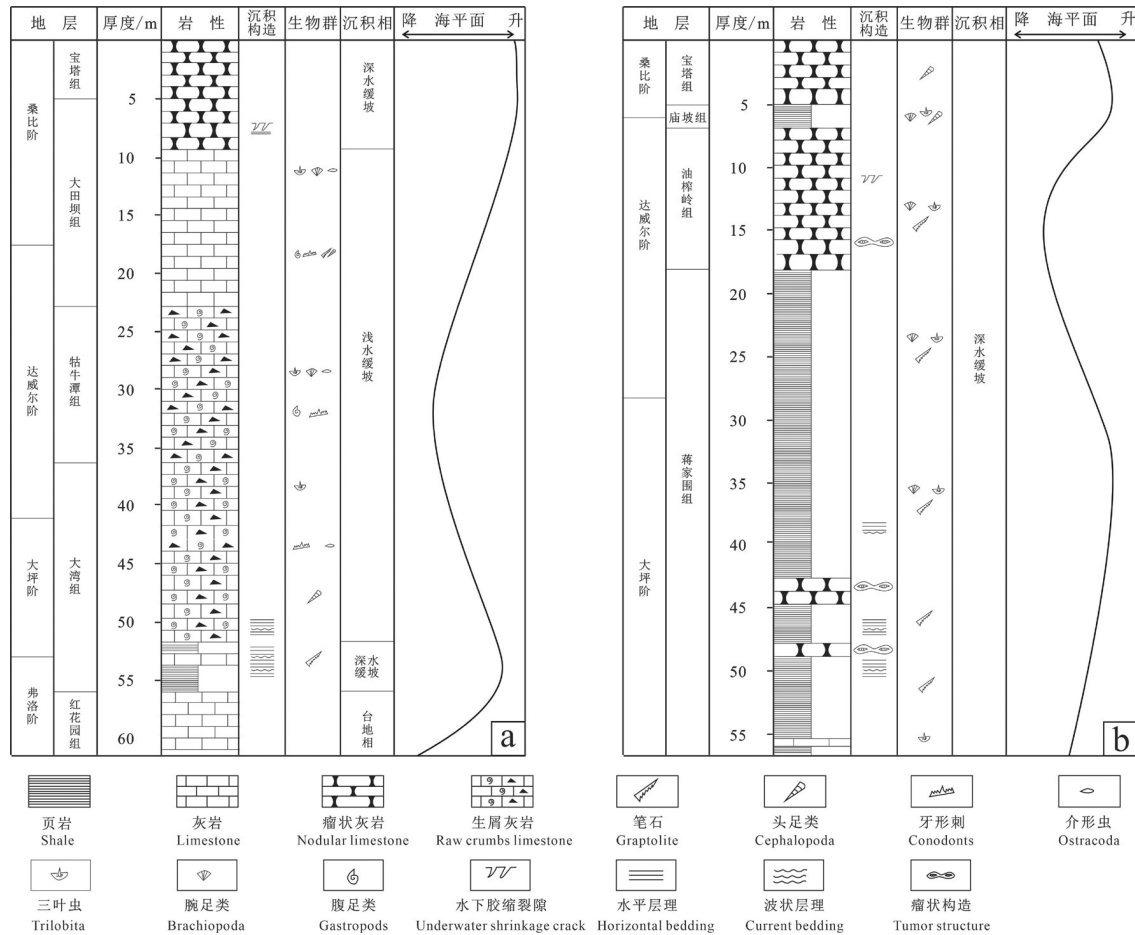


图4 下扬子地区碳酸盐岩缓坡相典型剖面沉积序列

a—安徽省无为横山宁国—胡乐期沉积相演变综合柱状图；b—安徽省宿松县龙山宁国—胡乐期沉积相演变综合柱状图

Fig.4 Sedimentary sequence of typical section of carbonate gentle slope facies in Lower Yangtze Region

a—Comprehensive column diagram of sedimentary facies evolution of Ningguo-Hule period in Hengshan section, Wuwei County, Anhui Province; b—Comprehensive column diagram of sedimentary facies evolution of Ningguo-Hule period in Longshan section, Susong County, Anhui Province

上部以骨屑微晶灰岩、泥质灰岩为主，不见海绿石和含磷质骨屑，并出现瘤状构造；浙江余杭荆山的闲林铺组岩性为灰白色厚层状结晶灰岩，厚度7.5 m。这些以灰岩为主，含少量泥质的沉积物，含丰富的腕足类、笔石和头足类化石，可能形成于稍浅水的缓坡环境中，可归于浅水缓坡；在和县、巢湖、无为、太湖、宿松一带，下部为灰绿、深灰色页岩夹薄层灰岩透镜体或灰岩条带，中部和上部沉积中厚层灰岩、生物碎屑灰岩，含丰富的头足类、腕足类、三叶虫和牙形刺等，这个页岩条带的形成可能是与海底古地形相关，该区刚好处于一个坡内洼地。与之对应的石台—青阳一线处于一个水下隆起区，发育紫红色、灰绿色厚层状微晶生物屑灰岩、含泥质瘤状生物屑微晶灰岩，富含海百合茎、头足类、牙形刺

和少量的腕足类、三叶虫等。其他皖南的大部分区域大湾组或者紫台组都是以瘤状灰岩、泥质灰岩沉积为主，属于深水缓坡沉积区。

碎屑岩沉积区从宁国—黄山—桐庐—兰溪一带、江西的赣东北一带，出露灰色、灰黑色页岩、粉砂质页岩，具水平层理，化石以营漂浮生活的笔石为特征，无底栖生物，发育浅水陆棚沉积，沉积中心位于广德—临安—桐庐一带，厚度可达120~180 m；而浙西南的三山地区宁国组页岩中普遍夹有薄层灰岩沉积，指示该区处于一水下低隆地带，水体相对较浅。

5.2 胡乐早期

胡乐早期碳酸盐岩沉积区岩性以骨屑亮晶灰岩—泥晶灰岩为主，指示水动力条件相对加强，海底相对变浅；而碎屑岩沉积区则发育硅质页岩，指示海

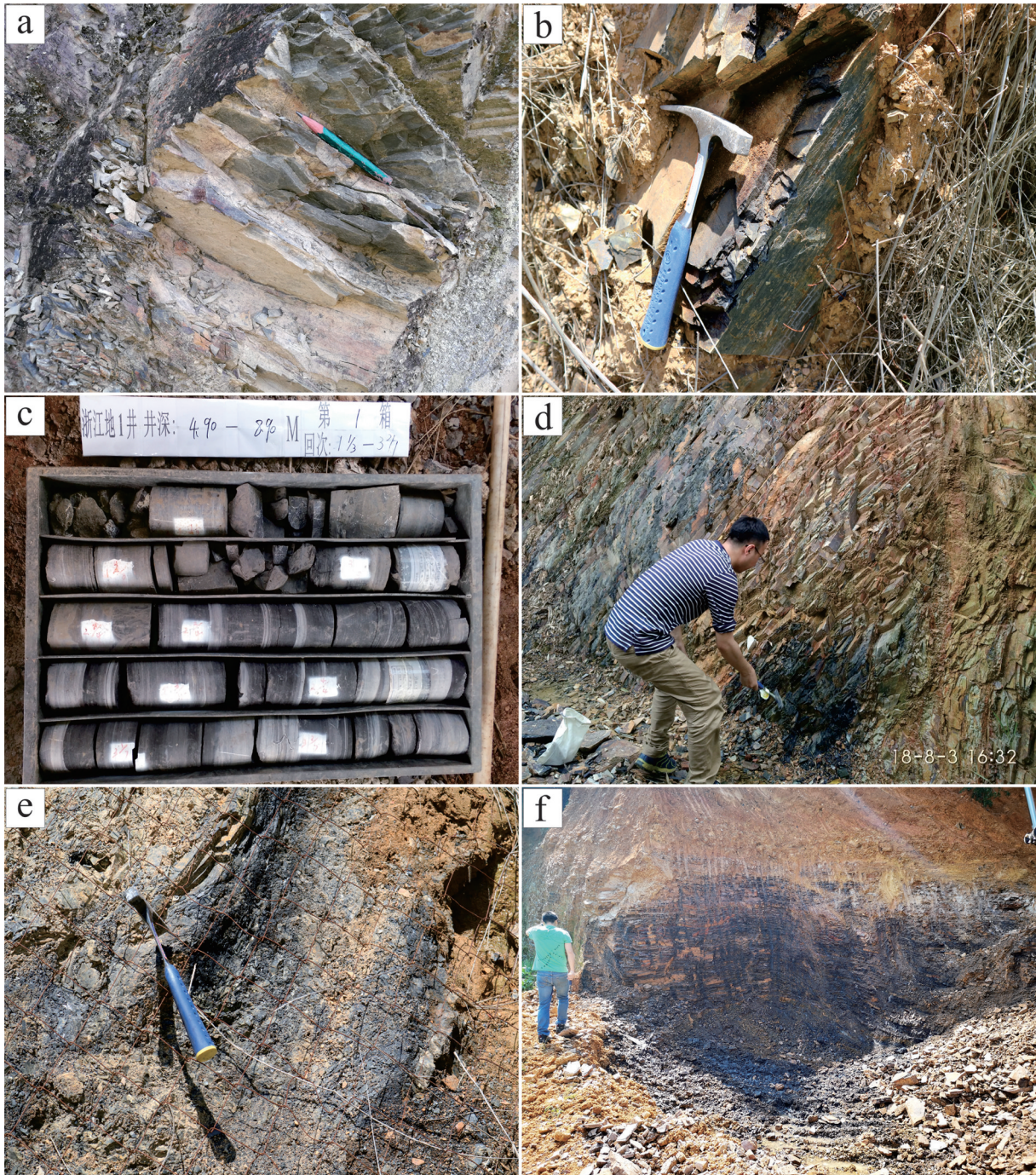


图5 下扬子地区宁国组—胡乐组岩性特征照片

a—灰色中薄层状粉砂质泥岩,浙江刘家剖面宁国组;b—灰黑色薄层状含粉砂笔石页岩,安徽胡乐镇将军岭剖面宁国组;c—灰黑色含炭泥岩夹薄—透镜状灰岩,浙江地1井宁国组;d—灰黑色硅质页岩,浙江刘家剖面胡乐组;e—灰黑色含炭硅质页岩,安徽胡乐镇将军岭剖面胡乐组;f—灰黑色硅质页岩夹薄层硅质岩,浙江坛石镇源东村胡乐组

Fig.5 Lithologic characteristics of the Ningguo Formation – Hule Formation in Lower Yangtze Region

a—Gray medium thin silty mudstone, Ningguo Formation, Liuji section, Zhejiang province; b—Gray-black thin layer silt-bearing penstone shale, Ningguo Formation, Junling section, Hule Town, Anhui Province; c—Gray-black carbonaceous mudstone with thin-lenticular limestone, Jingningguo Formation, ZJD1, China; d—Gray-black siliceous shale, Hule Formation, Liuji section, Zhejiang Province; e—Gray-black carbonaceous siliceous shale, Hule Formation, Changjunling section, Hule Town, Anhui Province; f—Gray-black siliceous shale with thin layer of siliceous rock, Hule Formation, Yuandong Village, Tanshi Town, Zhejiang Province

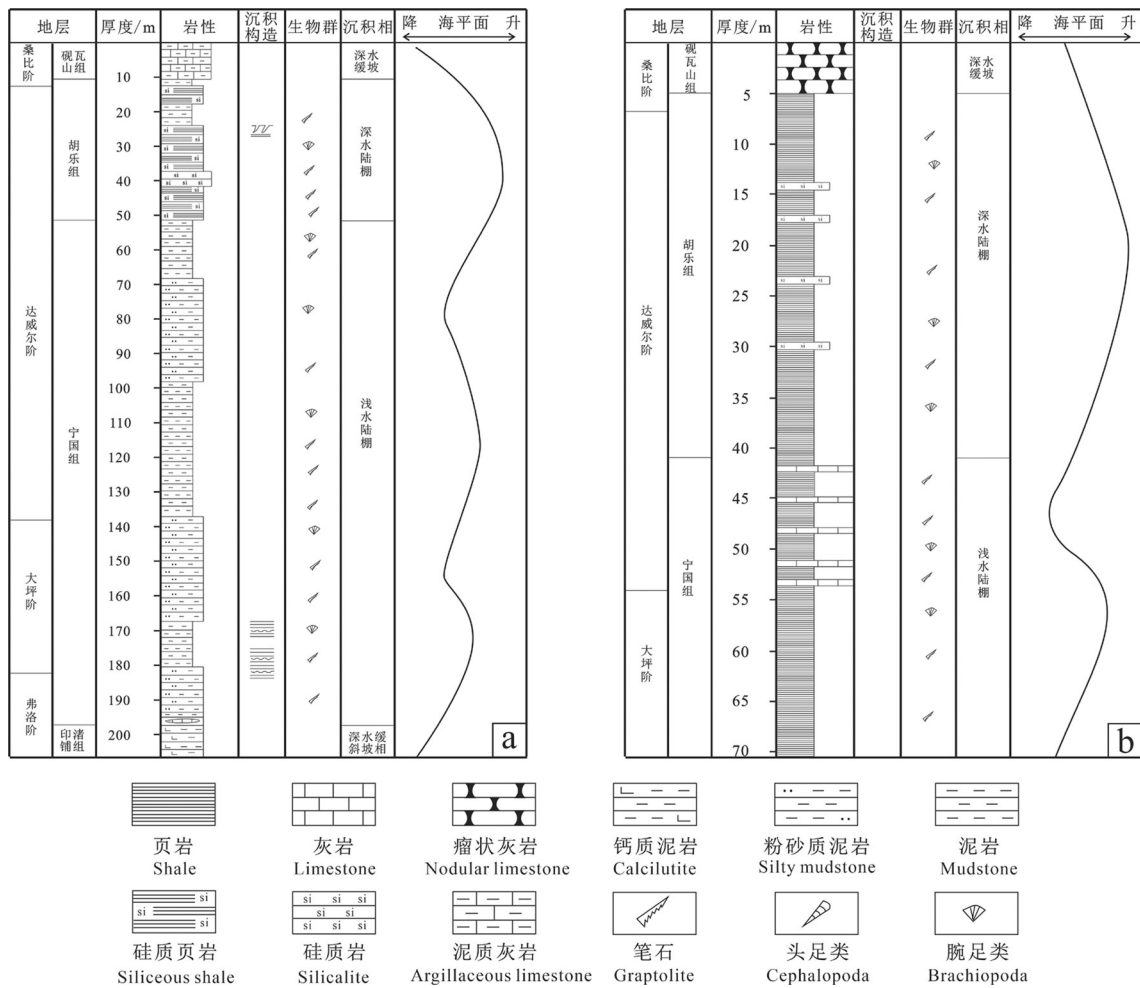


图6 下扬子地区浅海陆棚相典型剖面沉积序列

a—浙江省桐庐刘家宁国组—胡乐期沉积相演变综合柱状图；b—浙江省常山县黄泥塘宁国—胡乐期沉积相演变综合柱状图

Fig.6 Sedimentary sequence of typical shallow sea shelf facies section in Lower Yangtze Region

a—Comprehensive column diagram of sedimentary facies evolution from Ningguo—Hule period in Liujia section, Tonglu County, Zhejiang Province; b—Comprehensive column diagram of sedimentary facies evolution of Ningguo—Hule period in Huangniantang section, Changshan County, Zhejiang Province

底相对变深,这种沉积差异可能与区域沉降不一致相关。受加里东运动影响,碎屑岩沉积区所处的挠曲盆地进一步加深,而碳酸盐岩沉积区所处的前渊隆起则相对抬升,出现海平面下降的趋势(图9)。

滁县地区胡乐早期(牯牛潭组)发育浅灰色中厚至厚层灰岩、生物碎屑灰岩,化石稀少,厚度仅6 m。和县—安庆一带沉积了灰红色中层状灰岩、泥质灰岩,富含头足类、三叶虫,厚14 m(安徽省地质矿产局区域地质调查队,1989a)。宁镇地区的牯牛潭组地表出露不多,厚度仅12 m左右,以灰黄色薄—中厚层状微晶生屑灰岩、粉屑石灰岩及含生物碎屑、粉屑微晶石灰岩为主,头足类和牙形石都很丰富。

浙江余杭留下剖面牯牛潭组岩性为灰色中层状微晶灰岩,含丰富的头足类、牙形石和三叶虫化石,可归于浅水缓坡;而在宿松、太湖地区沉积了灰绿、黄绿色页岩、钙质泥岩夹灰岩瘤状体,含三叶虫和少量的笔石;东至—石台—泾县一带,以灰绿色中厚至厚层状泥质瘤状灰岩,有些地区还夹2~3层三叶虫碎屑层,上部含龟裂纹,该区水体较深,沉积物中黏土含量增加,属于局限的深水缓坡环境。

碎屑岩沉积区普遍发育一套灰黑色硅质炭质页岩,富含笔石,且较宁国组的页岩粉砂含量减少,硅质含量显著增加,显示出饥饿沉积特征,发育深水陆棚沉积。在黄山谭家桥和宁国一带形成两个

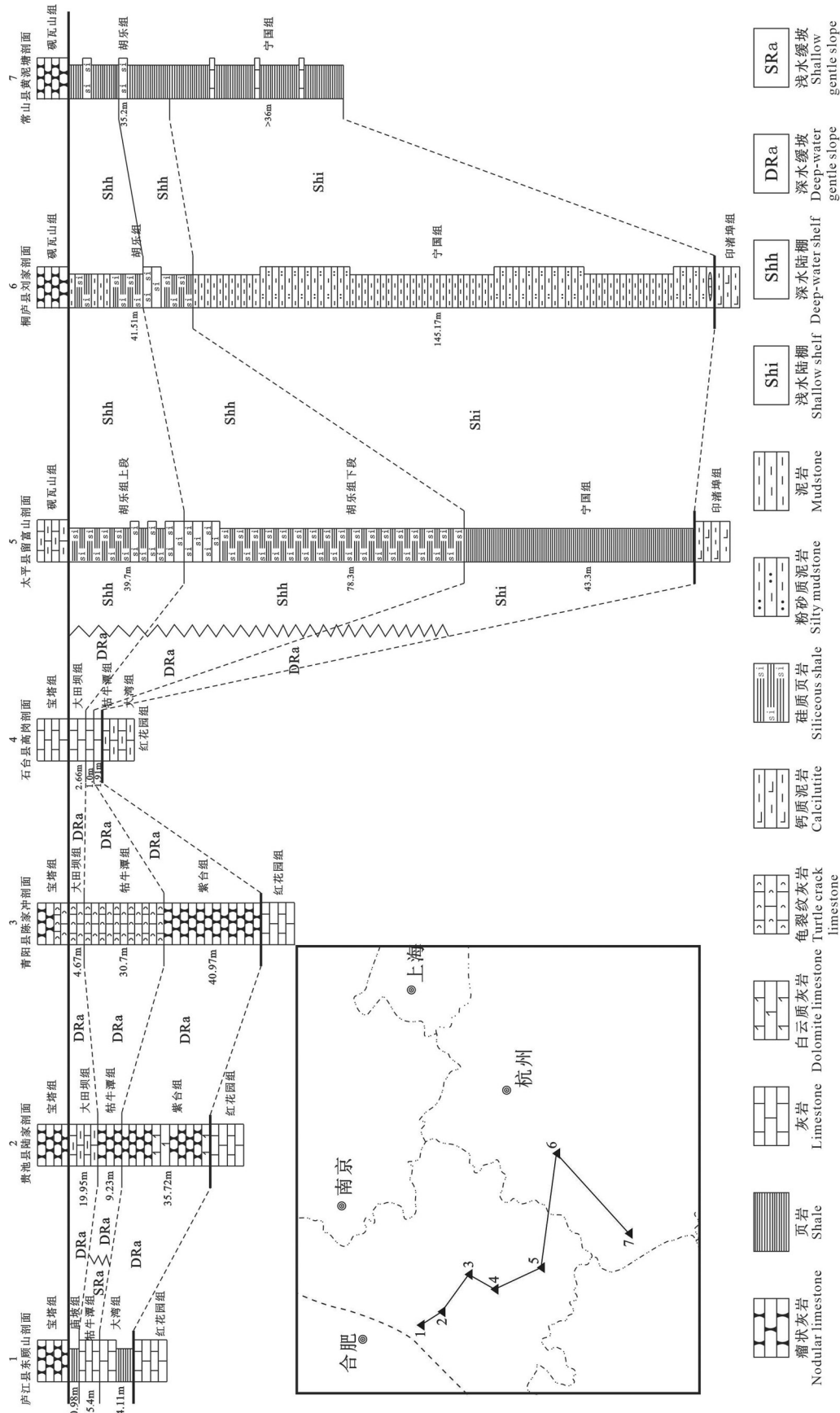


图7 下扬子地区中奥陶世宁国—胡乐期沉积相对比图

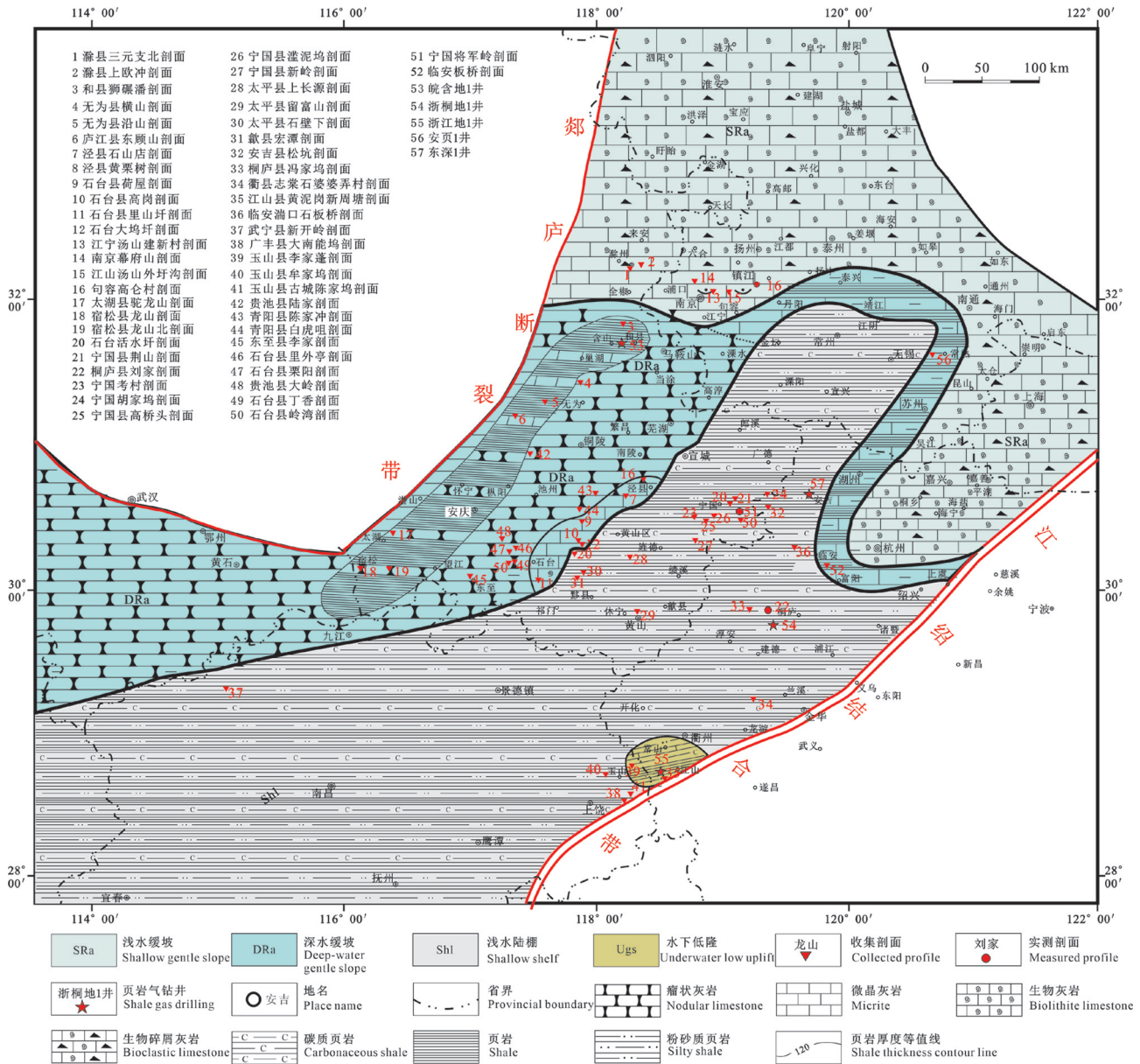


图8 下扬子地区宁国期岩相古地理

Fig.8 Lithofacies palaeogeography of the Ningguo period in the Lower Yangtze Region

条条形呈北东东和北东方向延伸的沉降中心。

5.3 胡乐晚期

胡乐晚期在经历了胡乐早期短暂海退之后再次发生海侵,皖东的和县—太湖—宿松一带发育庙坡组,岩性为黑色页岩夹灰岩,呈“补丁状”嵌入大田坝组沉积区。滁县的三元支组下部(相当于大田坝期的沉积)为紫红色含钙质结核泥质灰岩、瘤状泥质生物灰岩,含少量的三叶虫。芜湖—南陵—石台—东至一线,普遍发育紫灰色中厚层泥质灰岩、瘤状灰岩夹生物碎屑灰岩,具龟裂纹状构造,含头足类

化石。整个安徽的碳酸盐岩沉积区发育深水缓坡沉积,局部的凹陷内发育页岩沉积。宁镇山脉地区的大田坝组厚度极薄,仅2~3 m厚,岩性为紫灰色中厚层状含泥质条带粉屑、骨屑微晶灰岩,层面具明显的收缩纹,与上覆的宝塔组灰岩相似,难以区分。昆山地区的昆2井揭示的大田坝组岩性为深棕色含重结晶微晶生物碎屑灰岩,生物碎屑以三叶虫为主,富产牙形刺。浙江余杭地区的荆山岭剖面大田坝组发育生物碎屑灰岩(陈旭等, 1981),宁镇—上海—余杭地区相对于安徽地区水体较浅,处于浅水缓坡。

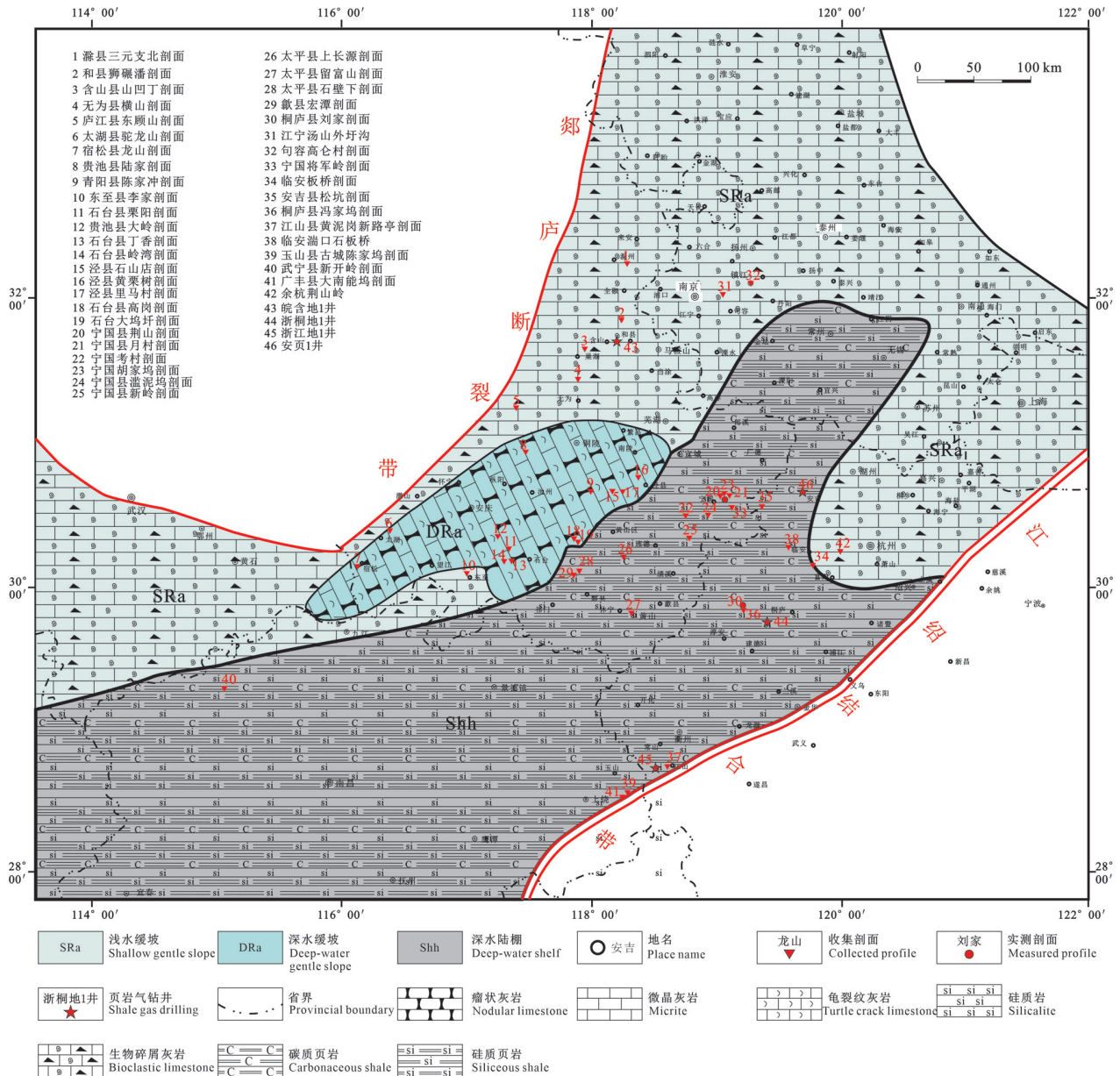


图9 下扬子地区胡乐早期岩相古地理

Fig.9 Lithofacies palaeogeography of the early Hule period in the Lower Yangtze Region

碎屑岩沉积区基本继承了胡乐早期的沉积特征,沉积了黑、灰黑色硅质岩、硅质页岩夹粉砂质页岩、含炭质页岩,化石以营漂浮生活的笔石为特征,无底栖生物。其沉降中心位于宁国月村—上荆山,经胡乐司至太平留富山一线,呈北东南西向的长条形,属深水陆棚沉积(图10)。

6 油气远景分析

宁国—胡乐组黑色富笔石页岩广泛分布于碎屑岩沉积区,厚度上百米,沉积环境为浅海陆棚,尤

其是胡乐组黑色富笔石硅质炭质页岩,是下扬子地区乃至整个中国南方新发现的一套烃源岩。近些年来随着下扬子地区页岩气勘探的不断深入,国内多家单位对该套层系开展了前瞻性研究,依据最新的野外露头样品和钻井地球化学测试结果,胡乐组有机碳含量0.5%~4%,平均在2%左右(浙桐地1井);宁国组页岩普遍含有粉砂质,有机碳含量相对较低,在0.2%~1%(安徽宁国胡乐镇将军岭剖面)(龚建明等,2017)。胡乐组页岩有机质类型以II₁干酪根为主,宁国组页岩有机质类型以I型干酪根为

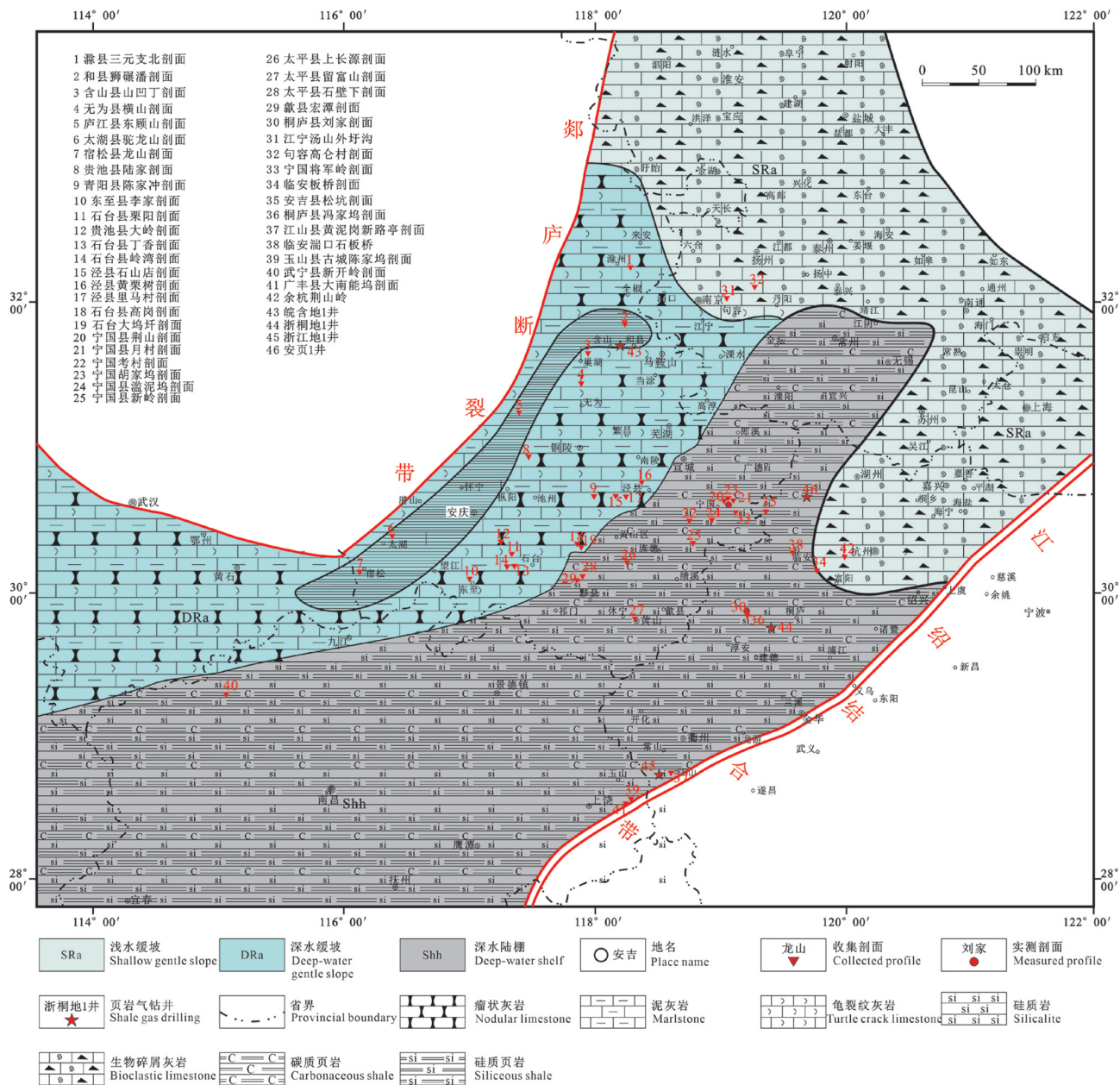


图10 下扬子地区胡乐晚期岩相古地理

Fig.10 Lithofacies palaeogeography of the late Hule period in the Lower Yangtze Region

主;胡乐组样品脆性矿物含量高,以石英为主,分布在44.9%~83.7%,平均68.15%(10个样品);宁国组样品脆性矿物含量略低,分布在27.6%~56.6%,平均41.6%(15个样品),都满足后期的压裂开发要求(黄邱贝, 2016)。依据以上参数综合评价胡乐组为好—中等烃源岩,宁国组为差烃源岩。

本次研究依据前人剖面资料和最新的钻孔、剖面数据,首次编制出下扬子地区胡乐组黑色页岩厚

度等值线图,图中揭示皖南的绩溪—旌德—宁国一线为深水陆棚的沉积拗陷区,该区域胡乐组黑色炭硅质页岩厚度相对稳定,均在100 m以上(图11),有机碳含量在2%左右,生烃潜力巨大,可作为整个下扬子地区页岩气勘探开发的油气远景区。

7 结论

(1)以“构造控盆、盆地控相、相控油气基本地

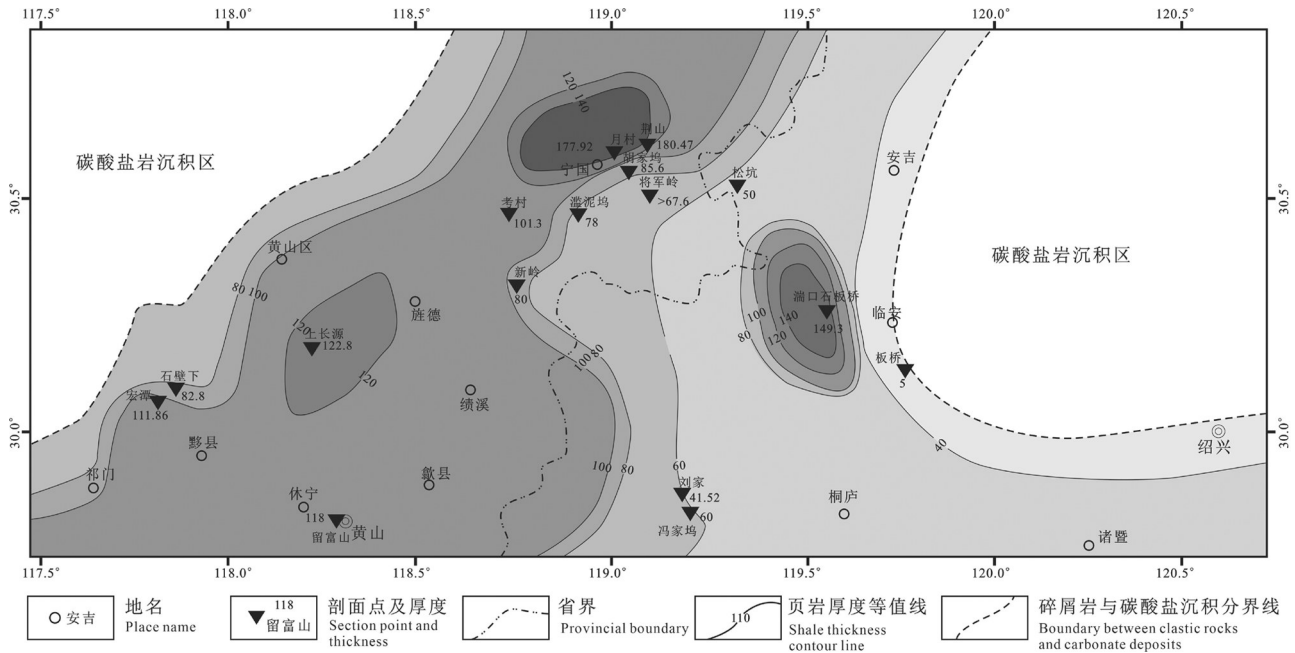


图 11 下扬子地区胡乐组黑色页岩厚度等值线图

Fig.11 Contour map of the thickness of black shale of Hule Formation in Lower Yangtze Region

质条件”理论为指导,指出中奥陶世受整个华南构造-沉积转型期影响,虽然下扬子地区古地理格局并未发生重大改变,但是构造环境已经由伸展状态转化为挤压状态。来自于加里东运动早期的构造挤压和全球海平面上升的叠加影响,碎屑岩沉积区由之前的相对浅水的钙质页岩夹灰岩条带沉积转化为更深水的笔石页岩沉积;碳酸盐岩沉积区由之前红花园期镶边型碳酸盐台地,转化为碳酸盐岩缓坡相龟裂纹灰岩和瘤状灰岩,沉积速率减慢,黏土质含量显著增加。

(2)根据下扬子地区奥陶纪宁国—胡乐期近60个剖面 and 最新页岩气钻孔资料,开展岩石学、古生物学、地球化学、沉积构造和沉积层序的分析,依据沉积物特征将下扬子地区划分为碳酸盐岩沉积区和碎屑岩沉积区,碳酸盐岩沉积区主要位于下扬子地区的北部、西部,南部和东南部,以碎屑岩沉积为主。采用优势相分析方法,碳酸盐岩沉积区主要发育碳酸盐缓坡相,可进一步划分为浅水缓坡和深水缓坡;碎屑岩沉积区主要发育一套细碎屑陆棚相,可细分为浅水陆棚和深水陆棚。

(3)通过对下扬子地区宁国—胡乐期沉积相及古地理方面的研究,认为胡乐期皖南的绩溪—旌德—宁国一线为深水陆棚的沉积拗陷区,页岩厚度普遍达

100 m 以上且有机碳含量在2%左右,有机质类型以II₁干酪根为主,生烃潜力巨大;脆性矿物含量高,达44.9%~83.7%,平均68.15%,利于后期的压裂开发,可与五峰组—高家边组黑色岩系一起作为下扬子地区下一步烃源岩及页岩气勘探开发的重点研究区。

注释

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