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珠江口盆地荔湾凹陷上渐新统—早中新统物源特征及其对沉积充填的影响

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提要:利用化学蚀变指数法恢复物源区的风化历史及沉积物通量是一种经济实用、行之有效的方法。前人对珠江口盆地荔湾凹陷对应物源区的研究相对薄弱。本文通过对区内岩心测试数据进行化学蚀变指数分析,恢复晚渐新世—早中新世物源区的风化历史,并进行沉积物通量的估算,在此基础上探讨物源特征对研究区内沉积充填的控制作用。研究表明,晚渐新世研究区对应物源区经历了强烈风化阶段,该阶段产生的丰富的沉积物供给是研究区西北部快速进积、规模壮观的陆架边缘三角洲及斜坡重力流沉积体系发育的重要控制因素之一;早中新世,西北物源区风化减弱,沉积供给减少,但研究区东部沉积物供应较西部要充分得多,表明早中新世,研究区南部除了来自西北部的主要物源外,局部物源对该时期的沉积具有重要影响;推测东部物源(东部古隆起、兴宁古隆起)的突然复活是促进研究区东部早中新世沟槽形成发育的重要原因之一。在超深水区进行沉积物源区的研究中,这种半定量的方法对盆内局部物源的确定具有重要的指示意义。

关 键 词:化学蚀变指数;物源;风化历史;沉积物通量;渐新世—中新世;油气勘查工程;荔湾凹陷;珠江口盆地

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Provenance feature of Upper Oligocene to Early Miocene in Liwan Sag, Pearl River Mouth Basin and its influence on depositional filling

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Abstract: The chemical alteration index method is an economic, practical and effective method for recovering the weathering

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history and sediment flux of the source area. The research on provenance feature of Liwan Sag, Pearl River Mouth Basin (PRMB), has been insufficient. In this paper, the weathering history and sediment flux of source area during late Oligocene to early Miocene were restored by analysis of chemical alteration index (CIA) based on the core data. In addition, their influence on depositional filling in the study area was also discussed. The results show that the source area during late Oligocene in the study area experienced a strong weathering stage, and the abundant sediment supply in this period constituted one of the important controlling factors for the rapid progradation and spectacular scale of shelf margin delta and gravity flow depositional systems in the northwest of the study area. On the other hand，during the early Miocene, the weathering of NW provenance area weakened and the sediment supply was reduced, but the sediment supply in the eastern area was more sufficient than that in the western part. It is shown that, in addition to the main provenance from the northwest, the local provenance had an important influence on the depositional infilling pattern during the early Miocene. It is inferred that the sudden resurrection of the eastern provenance, i.e., the Eastern Paleo- uplift and the Xingning Uplift, constituted one of the important control factors for the formation and development of the early Miocene grooves in the eastern area. In the study of sediment source area in the ultra-deep water area, the semi-quantitative method of CIA has certain indicative meaning for the determination of local provenance in basin.

Key words: CIA (Chemical Alteration Index); provenance; weathering history; sediment flux; Oligocene- Miocene; oil and gas exploration engineering; Liwan Sag; Pearl River Mouth Basin

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1 引 言

化学蚀变指数（Chemical index of alteration，CIA）在分析物源区的风化程度(Fedo et al., 1995)、古气候(Yang et al., 2014; Passchier et al., 2017; 赵占仑等，2018)、源汇系统(杨江海，马严，2017)等方面有重要指示作用(徐小涛，邵龙义，2018)。该指数主要反映硅酸盐的风化，若不存在元素迁移后再沉积的情况，其可以很好地反映沉积物形成期的化学风化情况(赵占仑，2018)。高CIA值表明风化过程中Na、K、Ca等元素相对于稳定的Ti、Al元素的大量流失，反映温暖、潮湿气候下相对较强的风化程度；相反，低CIA值反映寒冷、干燥气候下相对较弱的风化程度(Fedo et al., 1995; 徐小涛，邵龙义，2018)。CIA=50~60，为弱风化程度；CIA=60~80，为中等风化程度；CIA=80~100，为强烈风化程度(Fedo et al., 1995)。Mclennan(1993)通过对世界上主要河流及其隆起剥蚀区通量的汇总，总结出风化历史与沉积物通量的相关关系，并提出了利用CIA进行物源区沉积物通量估算的公式。

珠江口盆地南部的荔湾凹陷现今位于洋陆过渡带附近的超深水区(何家雄等，2009; 纪沫等，2014)。晚渐新世研究区西北部发育规模壮观的陆架边缘三角洲及重力流体系(Lin et al., 2018; Zhang et al., 2019)；早中新世，研究区东部发育数十条千米尺度的沟槽体系(Sun et al., 2016; 邢作昌等，2019)及大型水道重力流体系(曾清波等，2013; 廖计华等，2016)。研究区内这些重要沉积体系（尤其是沟槽体系）的沉积机制存在较大争议，其控制因素仍需进一步明确。物源研究，作为控制沉积体系研究的关键控制因素之一，尤其是近年来源汇系统受到重视，更加受到沉积学家的关注(林畅松等, 2015; Bhattacharya et al., 2016; 甄甄等, 2018; 孙宁亮等, 2019)。但珠江口盆地荔湾凹陷对应物源区的研究却十分薄弱。本文利用珠江口盆地南部荔湾凹陷内宝贵的岩心岩屑资料，通过化学蚀变指数的分析来反演研究区珠海组—珠江组沉积期对应物源区的风化历史，并进行沉积物通量的恢复，以期为研究区内沉积体系的成因机制及其控制因素的揭示提供新的证据。

2 地质概况

研究区现今位于南海北部陆缘珠江口盆地下

陆坡的荔湾凹陷内（图1a）。该凹陷是珠四凹陷洋陆过渡带之上的超深水凹陷，北以云荔低隆起与白云凹陷相邻，南部与南海西北次海盆相接，东部以兴荔凸起与兴宁凹陷相望，面积约2.5×10^4 km^2，水深2000~3000 m，呈现出南深北浅的特点（图1b），属于超深水区(何家雄等，2009; 纪沫等，2014)。

研究区位于处在明显减薄的大陆边缘细颈化带—远端带内(任建业等,2014)，主要经历了早期海底扩张(裂后−断坳过渡期)、晚期海底扩张（裂后坳陷期）、后海底扩张三大阶段（图2）(林畅松等，2018)。自底到顶依次沉积了古近系文昌组、恩平组和珠海组，新近系珠江组、韩江组、粤海组和万山组，以及第四系(庞雄等，2007; Sun et al., 2016; 邢作昌等，2019; Xie et al., 2019)。本文重点关注研究区内的中晚渐新世珠海组和早中新世珠江组，是珠江口盆地油气勘探的重点关注层位，同时其与南海破裂不整合层序的关系密切(Morley, 2016; Lin et al., 2018; Gong et al., 2019)，是近年来国内外油气勘探及科学研究的热点层段。

3　研究方法及结果

研究区现今水深2000~3000 m，从海洋油气勘探深度上看，属于超深水区。目前钻井稀少，仅有A、U1501两口钻井（图1）。A井位于研究区西北部，为油田勘探钻井，岩心资料以岩屑为主，无完整岩心，其样品分析数据来源于中海油深圳分公司研究院；而B井位于研究区东南部，为国际大洋钻探科学钻井，全井段取心，其样品分析数据源于IODP网站（https://doi.org/10.14379/iodp.proc.367368.105.2018）。

本文利用研究区内这两口钻井获得的常量元素分析数据计算其化学识别指数（CIA）并估算沉积物通量。大致过程如下：利用岩屑或岩心样品得到岩石的常量元素分析资料，把其中需要的Al_2O_3、CaO、Na_2O、K_2O、P_2O_5等氧化物的数据转化为分子摩尔数据（注意，CaO^*的计算方法是：$CaO_{剩余}=CaO-P_2O_5\times10/3$，如果$CaO_{剩余}<Na_2O$，则$CaO^*=CaO_{剩余}$；反之，若$CaO_{剩余}>Na_2O$，则令$CaO^*=Na_2O$），然后带入公式($CIA=[Al_2O_3/(Al_2O_3+CaO^*+Na_2O+K_2O)]\times100$)计算得出CIA值。参考Fedo et al.(1995) CIA值判断物源区的风化程度：CIA=50~60，为弱风化程度；CIA=60~80，为中等风化程度；CIA =80~100，为强烈风化程度。再次，根据Mclennan et al.(1993)总结的经验公式：

$$沉积物通量/(t/km^2\cdot a) = (2.25\times10^5)(10^{-0.0435[CIA]})$$

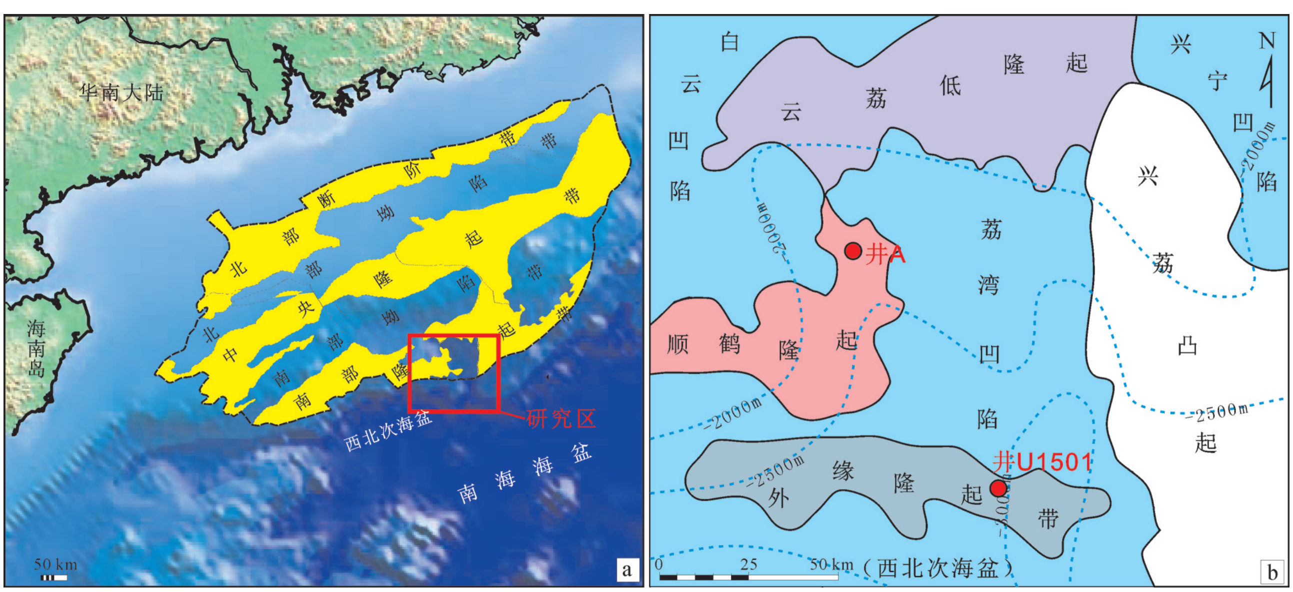

图1　研究区位置(a)及构造单元划分(b)
(图a红色方框示意b图范围;图b蓝色虚线示意现今水深,引自袁立忠等,2017)
Fig.1　Location (a) and structural unit division (b) of the study area
(Note that the red box in Fig. a indicates the range of Fig. b and the dash blue line in Fig. b shows the current water depth contour after Yuan Lizhong et al., 2017)

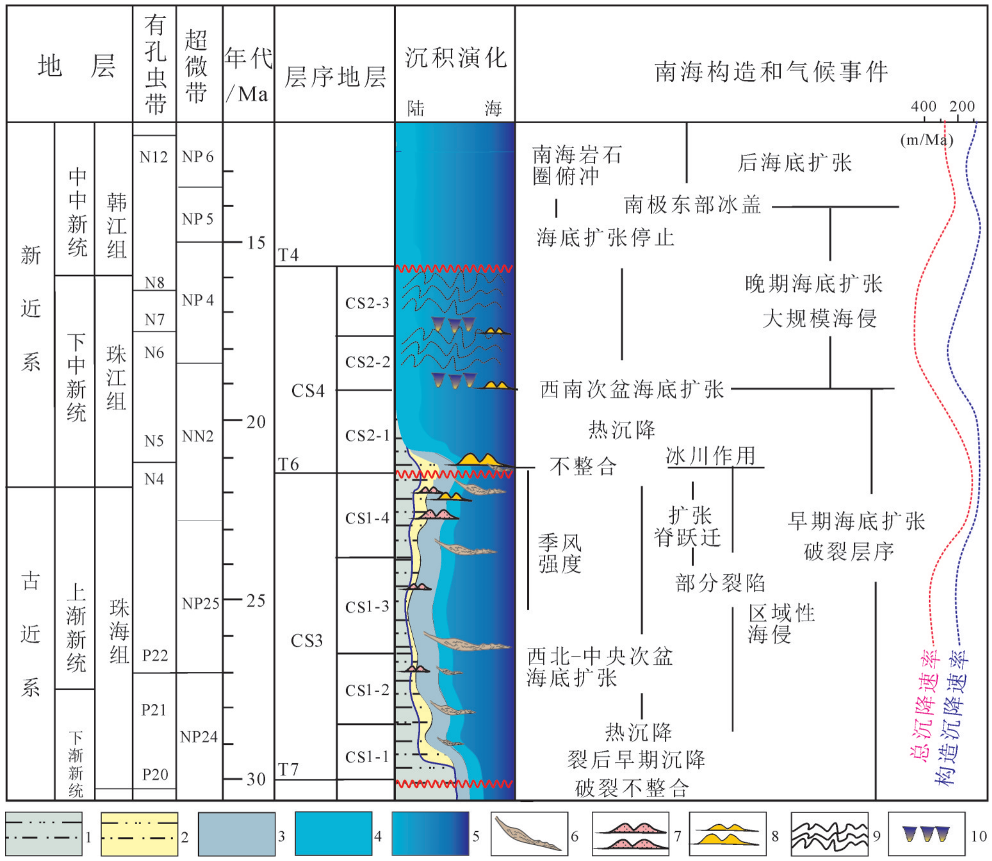

图2 荔湾凹陷渐新统—下中新统综合柱状图

1—外陆架沉积;2—陆架边缘沉积;3—上陆坡沉积;4—中陆坡沉积;5—下陆坡—深海沉积;6—块体搬运沉积;7—前三角洲浊积扇;8—斜坡扇—海底扇沉积;9—大规模变形层;10—沟槽。地层划分据庞雄等(2006);有孔虫、钙质超微化石定年据Jian et al.(2018)资料整理;层序地层、构造和气候事件、沉降曲线引自林畅松等(2018)

Fig.2 The comprehensive histogram during Oligocene to lower Miocene of Liwan Sag, PRMB

1-Outer shelf deposits;2-Shelf margin deposits;3-Upper slope deposits;4-Middle slope deposits;5-Lower continental slope-abyssal deposits;6-Mass transport deposits;7-Prodelta turbidite fan;8-Slope-basin fan;9-Large-scale deformed beds;10-Grooves. stratigraphic divisions after Pang Xiongqi et al.,2006; foraminifera and calcareous nanofossils zones after Jian et al., 2018; sequences classification, tectonic and climatic events mainly after Lin Changsong et al. 2018a

过程参数及研究区的沉积物通量详见表1和表2。

4 讨 论

4.1 钻井揭示的风化历史及沉积物通量特征

研究区西北部A井珠海组的CIA为70~83(表1),表明晚渐新世物源区风化程度为中等风化~强烈风化(参照Fedo et al., 1995标准;下文类似);而珠江组的CIA为69~79(表1),属于中等程度风化。从CIA垂向的变化曲线上看,中晚期珠海组的CIA值在80上下波动,对应物源区强烈风化阶段;而早中新世,物源区的风化作用减弱(图3),加之陆架坡折向北跃迁出研究区(柳保军等,2011),研究区整体沦为深水斜坡环境。注意CIA曲线在渐新世末(或早中新世初)的突变(图3),代表晚渐新世强烈风化阶段突变为早中新世初的中等风化阶段,是区域广泛发育复合层序界面CSB4的反映(Lin et al., 2018a),对应白云运动、南海洋中脊跃迁等重要的构造事件(庞雄,2007; 林畅松,2018; Lin et al., 2018b; Xie et al., 2019),进一步表明重大构造事件对研究区乃至物源区的重要控制作用。沉积物通量晚渐新世53.1~196.1 t/km^2·a,早中新世89.7~216.9 t/km^2·a(表1),整体变化不大(图3),是早中新世研究区东部存在局部物源的间接证据。

研究区东南部U1501井珠海组的CIA为63~

表1 研究区西北部A井CIA、沉积物通量计算一览表

Table 1 Calculation list of CIA and sediment flux in well A, northwest of the study area

地层	深度/m	原始数据				分子摩尔数据				CIA	沉积物通量
		Al_2O_3	CaO	K_2O	Na_2O	Al_2O_3	CaO^*	Na_2O	K_2O		/(t/km^2·a)
珠江组	3088	16.70	11.078	2.917	0.605	0.1638	0.0098	0.0098	0.0310	76	106.7
	3112	16.72	8.069	2.817	1.086	0.1639	0.0175	0.0175	0.0300	72	172.7
	3166	9.88	11.517	1.647	0.657	0.0969	0.0106	0.0106	0.0175	71	175.4
	3190	11.78	13.085	1.907	0.511	0.1155	0.0082	0.0082	0.0203	76	112.8
	3208	9.50	15.034	1.651	0.559	0.0932	0.0090	0.0090	0.0176	72	160.2
	3232	9.91	13.834	1.744	0.758	0.0972	0.0122	0.0122	0.0186	69	216.9
	3253	16.19	11.922	2.842	0.609	0.1588	0.0098	0.0098	0.0302	76	110.1
珠海组	3283	14.75	10.726	2.611	0.354	0.1447	0.0057	0.0057	0.0278	79	84.9
	3304	17.12	6.450	3.068	0.444	0.1679	0.0072	0.0072	0.0326	78	89.7
	3316	16.35	9.113	2.639	0.430	0.1603	0.0069	0.0069	0.0281	79	80.2
	3331	17.57	6.722	2.843	0.495	0.1723	0.0080	0.0080	0.0302	79	83.6
	3349	19.13	5.085	3.006	0.548	0.1876	0.0088	0.0088	0.0320	79	81.7
	3379	16.83	11.262	2.545	0.384	0.1650	0.0062	0.0062	0.0271	81	69.5
	3391	18.75	0.622	2.753	0.494	0.1838	0.0080	0.0080	0.0293	80	72.6
	3412	16.36	4.560	2.560	0.329	0.1603	0.0053	0.0053	0.0272	81	68.1
	3424	20.13	0.387	3.070	0.426	0.1973	0.0069	0.0069	0.0327	81	67.7
	3430	16.92	1.362	2.246	0.284	0.1659	0.0046	0.0046	0.0239	83	53.1
	3463	17.08	2.559	2.836	0.398	0.1675	0.0064	0.0064	0.0302	80	77.8
	3484	19.42	1.325	2.895	0.430	0.1904	0.0069	0.0069	0.0308	81	67.4
	3508	17.01	0.784	4.095	0.575	0.1668	0.0093	0.0093	0.0436	73	152.3
	3532	8.74	4.384	2.346	0.301	0.0857	0.0049	0.0049	0.0250	71	179.8
	3544	9.63	3.237	2.854	0.292	0.0944	0.0047	0.0047	0.0304	70	196.1
	3568	14.66	1.459	2.969	0.384	0.1437	0.0062	0.0062	0.0316	77	105.0

注：A为岩屑样品，表中深度基准面为海平面，原始测试数据源自中海油深圳分公司研究院。

72；而珠江组的的CIA为61~67（表2），从数值上看两者均属于中等程度风化阶段。但从CIA垂向的变化曲线上看，珠海组的CIA值在均值66上下波动非常剧烈（图4），根据Clift et al. (2002)的研究，晚渐新世南海北部存在强烈的季风增强事件。CIA的剧烈震荡可能是物源区剧烈变动气候事件的响应。剧烈变动的气候条件会加剧剧烈物源区的风化作用从而促进沉积物供给。根据化学蚀变指数得到研究区中晚渐新世的沉积物通量在173.7~407.9 t/km^2·a，其大小与恒河、黄河、密西西比河等现代输砂量较大的河流的沉积物通量相似（图5）。而之后的早中新世，CIA的波动要小得多。但沉积物通量的变化曲线显示，研究区渐新世的沉积物通量明显要比早中新世大的多（图4）。两者的突变界同样是区域地质事件（南海洋中脊跃迁事件、区域热沉降开始）的响应（图5）。

4.2 渐新世—中新世风化-剥蚀强度与沉积充填

大量的地震相分析工作表明，研究区珠海组中上部沉积充填以大型陆架边缘三角洲及各类斜坡重力流沉积为主（图2，图6a，图7），其中陆架边缘三角洲对应大型楔形高角度S型、S-斜交复合前积反射地震相，以具有巨厚三角洲前缘、前三角洲泥沉积为特征，而斜坡重力流沉积包括前三角洲浊积扇、泥石流为主等块体搬运沉积、水道化斜坡扇、盆底扇等沉积类型。早中新世珠江组内的沉积充填则以沟槽体系及白云—荔湾深水水道体系为代表（图6b，图8），且主要分布在研究区东部；其中沟槽体系具有数量多（44条）、下切深度变化大（36.4~112 m）、部分底部具有强振幅异常充填、平面近东西向展布、整体分布在东部古隆起以西等特点（图8）。海底类似线形沟槽的成因一直是近年来沉积学和古海洋学研究的重点内容（邢作昌等，2019）。

表2 研究区东南部U1501井CIA、沉积物通量计算一览表

Table 2 Calculation list of CIA and sediment flux in well U1501, southeast of the study area

地层	深度/m	原始数据				分子摩尔数据				CIA	沉积物通量
		Al_2O_3	CaO	K_2O	Na_2O	Al_2O_3	CaO^*	Na_2O	K_2O		($t/km^2 \cdot a$)
珠江组	183.1	14.48	27.88	2.46	1.66	0.142	0.0267	0.0267	0.0262	64	366.8
	196.3	15.29	23.63	2.45	1.57	0.150	0.0252	0.0252	0.026	66	296.5
	204.7	14.53	27.82	2.34	1.68	0.143	0.0271	0.0271	0.0248	64	358.4
	213.8	15.88	24.45	2.68	1.71	0.156	0.0275	0.0275	0.0285	65	331.8
	223.6	13.35	35.39	2.01	1.72	0.131	0.0277	0.0277	0.0214	63	409
	232.8	13.58	34.26	2.05	1.75	0.133	0.0282	0.0282	0.0218	63	409.8
	242.3	14.74	28.34	2.26	1.80	0.145	0.0290	0.029	0.024	64	378.7
	252.9	15.46	26.4	2.45	1.64	0.152	0.0265	0.0265	0.0261	66	310.6
	261.7	14.35	30.85	2.49	1.55	0.141	0.0250	0.0250	0.0265	65	342.2
	269.3	14.38	32.51	2.38	1.50	0.141	0.0242	0.0242	0.0253	66	313.1
	282.2	14.03	31.91	2.38	1.42	0.138	0.0229	0.0229	0.0253	66	305.4
	288.9	15.62	25.28	2.62	1.48	0.153	0.0239	0.0239	0.0279	67	275.5
珠海组	297.6	10.68	45.46	1.86	1.30	0.105	0.0210	0.0210	0.0198	63	412.5
	307.4	17.62	5.58	3.23	1.71	0.173	0.0276	0.0276	0.0344	66	306.9
	315.6	17.45	6.03	3.29	1.65	0.171	0.0266	0.0266	0.0350	66	303.5
	328.2	16.88	3.21	2.88	1.94	0.166	0.0313	0.0313	0.0306	64	371.2
	337.8	20.32	1.54	2.89	1.69	0.199	0.0273	0.0273	0.0307	70	202.3
	347.9	18.97	3.59	2.35	2.19	0.186	0.0353	0.0353	0.0250	66	301.7
	353.6	19.93	2.07	2.36	2.13	0.195	0.0344	0.0344	0.0251	68	259
	365.0	19.97	2.8	2.36	2.06	0.196	0.0332	0.0332	0.0251	68	244.5
	374.5	17.54	2.55	2.53	2.13	0.172	0.0344	0.0344	0.0269	64	360.3
	383.2	17.17	1.89	2.79	2.19	0.168	0.0338	0.0353	0.0297	63	407.9
	393.8	20.01	1.05	2.63	1.94	0.196	0.0188	0.0313	0.0280	72	173.7
	403.0	19.38	1.27	2.72	2.03	0.190	0.0227	0.0327	0.0289	69	218.6

注：U1501井珠江组主要为富黏土软泥，珠海组以微化石软泥、富微化石黏土为主；表中深度基准面为海底，原始测试数据引自国际大洋钻探网站https://doi.org/10.14379/iodp.proc.367368.105.2018。

晚渐新世物源区经历强烈风化作用(图3)，表明物源区强烈隆升(Lin et al., 2018b)，在强烈季风气候(Clift et al., 2002)的叠加作用下(图2)，物源区产生充足的物源供给，为研究区西北部大规模的陆架边缘三角洲体系及各类斜坡重力流沉积体系提供了源源不断的沉积物供给(图6，图7)。这种充足的沉积物供给条件造就了珠海组中上部的以大型陆架边缘三角洲及重力流体系为特色的强烈进积层序(图7; Lin et al., 2018b; 邢作昌，2019)，对应沉积表现为整个白云凹陷—荔湾凹陷内大规模前积层(延伸超过40 km)呈正常或“平顶”结构并不断向东南推进(图7; 曾清波等, 2015; Lin et al., 2018; Zhang et al., 2019)。

早中新世，物源区整体表现为中等风化阶段(图3，图4)。但研究区东南U1501井揭示的珠江组的沉积物供应通量平均为341.5 $t/km^2 \cdot a$，而研究区西北A井珠江组平均沉积物通量为136.6 $t/km^2 \cdot a$，前者是后者的近3倍。该证据表明早中新世，研究区南部除了接受来自西北部古珠江水系的主要物源外，区内局部物源对该时期的沉积充填具有重要影响(图6)。研究区东部存在兴荔凸起、东部古隆起等近南北向展布的古隆起(图6)，这些局部隆起在地震、构造和沉积过陡、热带飓风、海啸、海底火山活动等多种触发机制(Talling et al., 2012; Shanmugam, 2013)，很可能引起区内古隆起附近的古斜坡发生滑坡或垮塌等重力流相关的事件沉积(Shannon et al., 2005; Shanmugam, 2007)。如东部古隆起之上的地层展布呈楔形不等厚形态，即距离东部古隆起越远的西部斜坡区，其地层越厚(a、b、c逐渐增厚，图8a)，是东部古隆起作为同沉积古隆起、直接提供物源的有力证据。同时，在东部古隆起以西的地区，沟槽底部具有

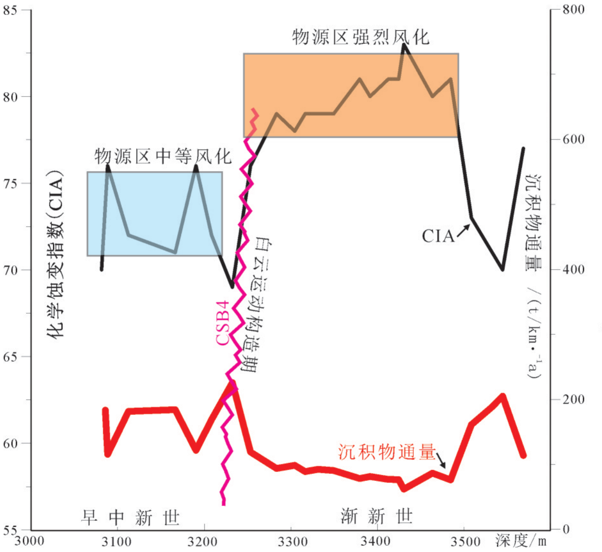

图3 研究区西北部A井揭示的CIA和沉积物通量折线图
Fig.3 Line chart of CIA and sediment flux revealed by well A in the northwest of the study area

楔形高振幅异常充填地震相，且高振幅异常带具有靠近隆起方向逐渐减薄、至隆起处消失的特征(图8a)，表明沟槽起源于东部古隆起西翼处。另外，早中新世研究区东部存在局部物源这一点同样被该时期U1501钻井的高沉积速率所证实：研究区内早中新世其沉积速率高达35 mm/ka，其值甚至比晚渐新世的沉积速率(13 mm/ka)高近2倍(图9)。早中新世如此高的沉积速率，表明研究区物源除了来自古珠江水系的远源物源外，区内近源的局部古隆起也可能是重要物源(图6)。该认识进一步确定了研究区沟槽发育期东部古隆起、兴宁古隆起等的供源作用。这个局部物源的发现在研究区内尚属首次，其意义在于表明即使在下陆坡—深海盆地的水下，区内隆起在一定的触发机制条件下，也可能形成规模较大的局部物源。该认识为南海早中新世走向延伸千米沟槽体系的成因机制提供了新的思路：前人认为海底类似线形沟槽的成因有斜坡失稳、块体滑塌、碎屑流、浊流等重力成因(Dowdeswell et al., 2008; Micallef and Mountjoy, 2011; Lonergan et al., 2013)和等深流等底流成因(Viana, 2008; Kilhams et al., 2011; Sun et al., 2016)两大类，而研究区内该局部物源的发现，表明沟槽体系的沉积物来自东部近物源，有力证实了南海这种特殊海底底形的重力流主导成因，而非前人认为的等深流等底流成因(Sun et al., 2016)。

总的来看，研究区珠海组中晚期物源区强烈风化，沉积物供给非常充分，为研究区渐新世中晚期陆架边缘三角洲体系及其伴生的重力流体系提供了充沛的物源供给；而之后的早中新世，西北物源区风化减弱，沉积供给减少，但研究区东部局部物源的供给使得研究区东部沉积物供应较西部要充

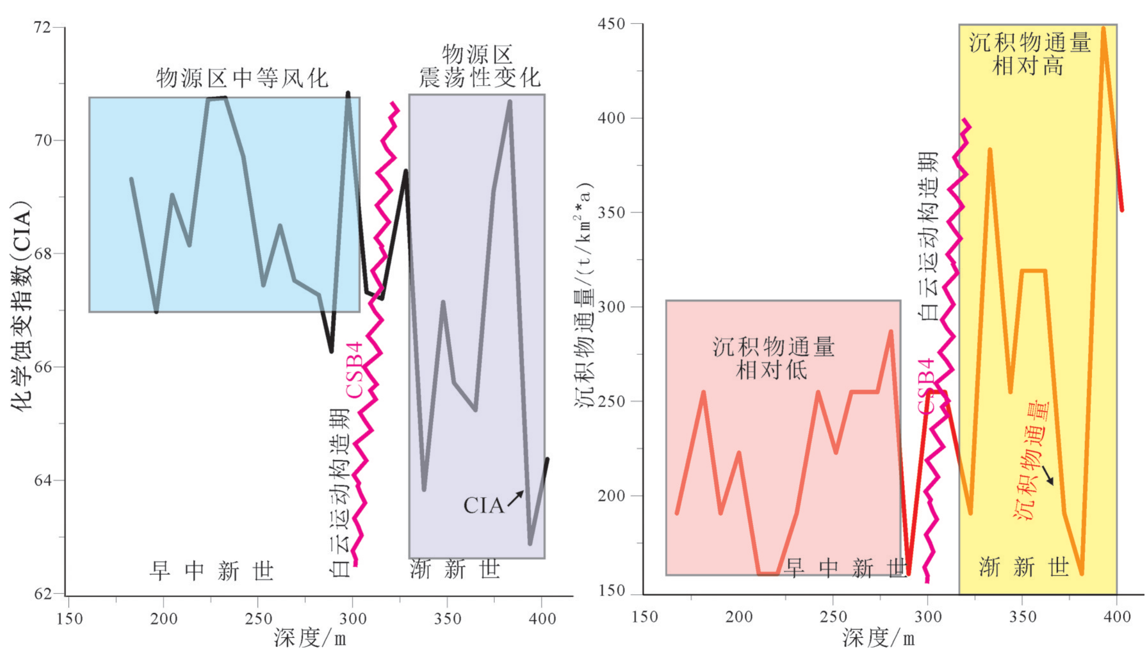

图4 研究区东南部U1501钻井揭示的CIA和沉积物通量折线图
Fig. 4 Line chart of CIA and sediment flux revealed by well A in the southeast of the study area

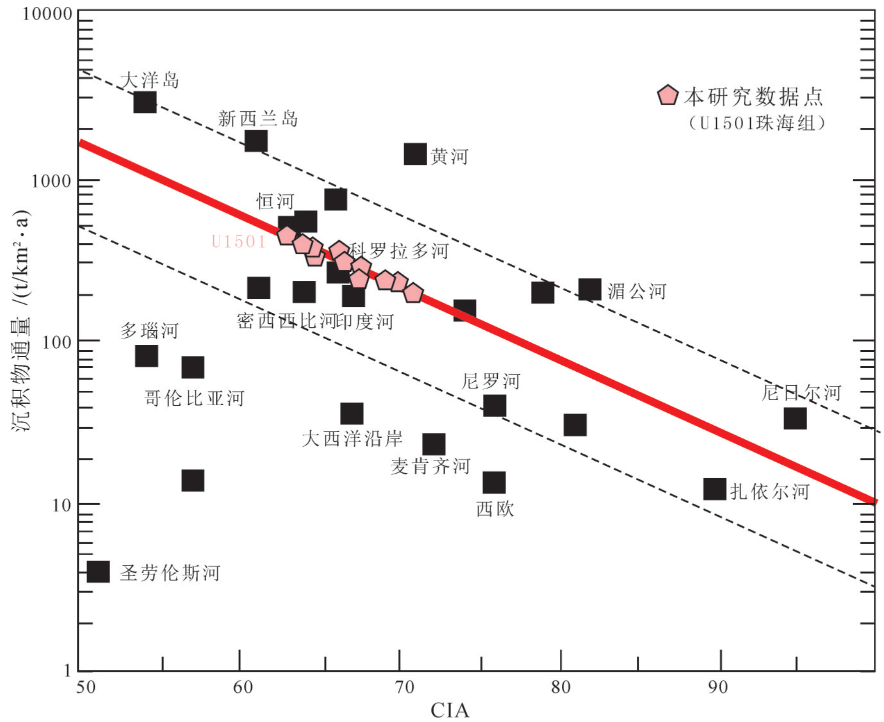

图5 研究区内沉积物通量与世界主要河流沉积物通量的比较(底图引自Mclennan, 1993)

Fig.5 Comparison of sediment fluxes between the study area and major rivers in the world (basemap from Mclennan, 1993)

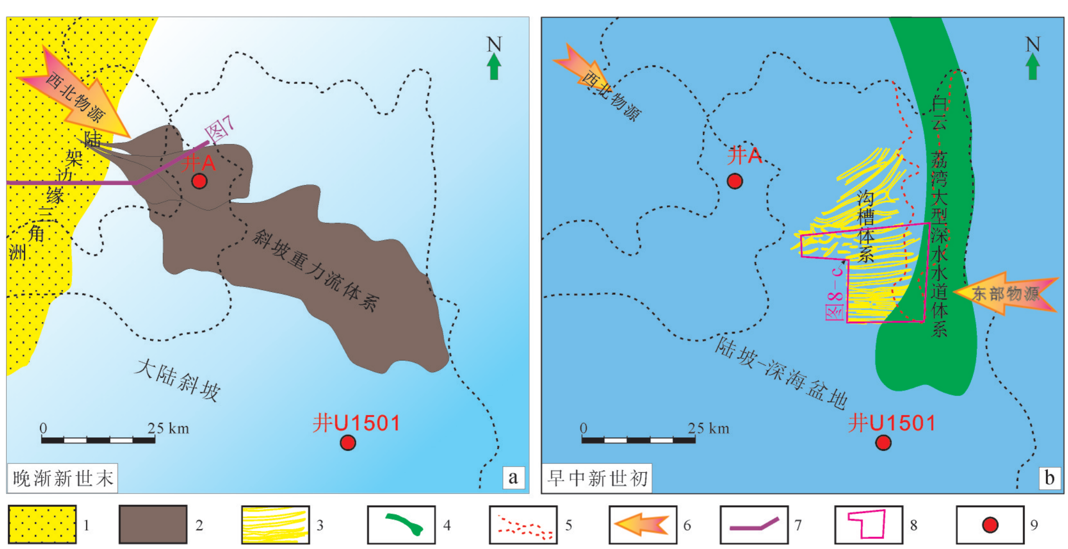

图6 研究区晚渐新世末、早中新世初沉积体系分布特征

1—陆架边缘三角洲沉积体系;2—斜坡重力流沉积体系;3—沟槽沉积体系;4—白云—荔湾大型深水水道体系荔湾凹陷段;5—东部古隆起;6—物源方向;7—图7平面位置;8—图8-c平面位置;9—钻井.图b中早中新世沟槽体系引自邢作昌等(2019);白云—荔湾大型深水水道体系引自廖计华等(2016)

Fig.6 Distribution of depositional systems in the study area during late Oligocene and early Miocene

1−Shelf margin delta;2−Slope gravity flow depositional systems ;3−Grooves depositional system;4−Deep water channel system of Baiyun−Liwan Sag;5−Eastern paleo−uplift;6−Source direction;7−Plan view of Fig. 7;8−Plan view of Fig.8 −c;9−Borehole the plan view of the grooves in Fig. b is after Xing Zuochang et al., 2019 ; the plane view of deep water channel system of Baiyun−Liwan Sag in Fig. b after Liao Jihua et al., 2016

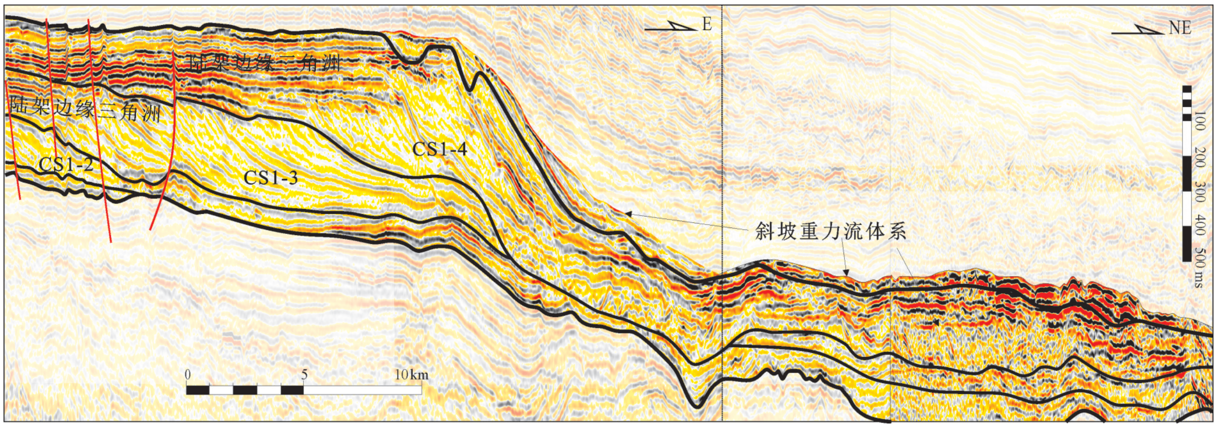

图7 研究区西北部晚渐新世陆架边缘三角洲–斜坡重力流沉积体系特征

Fig.7 Features of the shelf margin deltas and slope gravity flow depositional systems during Late Oligocene in northwestern study area

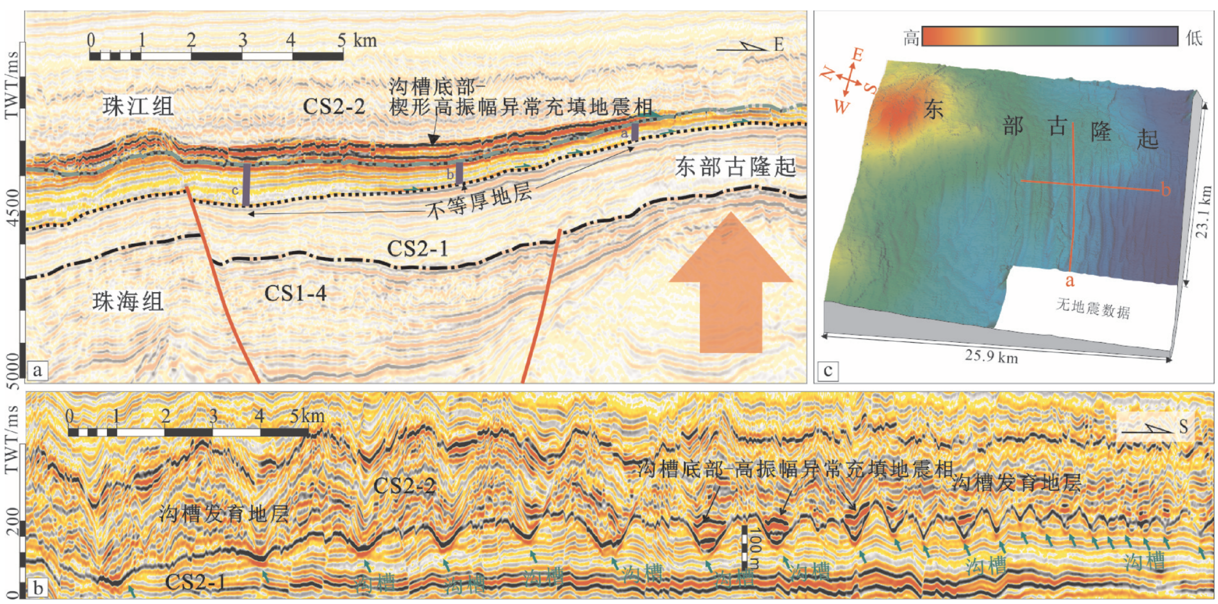

图8 研究区东部早中新世沟槽沉积体系特征

Fig.8 Features of the grooves' depositional system during early Miocene in eastern study area

分的多，东部局部物源的突然复活为区内沟槽体系的形成发育提供的直接物源，有力证实了南海这种特殊海底底形的重力流主导成因。

5 结　论

珠江口盆地荔湾凹陷内的化学蚀变指数法恢复风化历史及沉积物通量的分析表明：

(1)研究区渐新世晚期CIA为70~81，表明物源区经历了强烈风化阶段，其反映了物源区强烈隆升与强季风的耦合作用；该阶段产生的丰富的沉积物供给（沉积物通量为173.7~407.9 t/km^2·a）是研究区西北部快速进积、规模壮观的陆架边缘三角洲及各类斜坡重力流沉积发育的重要控制因素之一。

(2)早中新世，西北物源区风化减弱，沉积供给减少，但研究区东南部的沉积物通量却较西北部大的多，表明研究区除了西北主物源外，东部也存在局部物源；早中新世的东部局部物源(东部古隆起、兴宁古隆起)的突然复活对区内沉积充填具有重要影响，推测其为沟槽体系的形成发育提供的直接物源，可能是南海这种特殊海底底形的重力流主导成因的有利证据。

(3)在超深水区进行沉积物源区的研究中，利用化学蚀变指数法恢复物源区的风化历史及沉积物通量是一种的经济实用、行之有效的方法，这种半

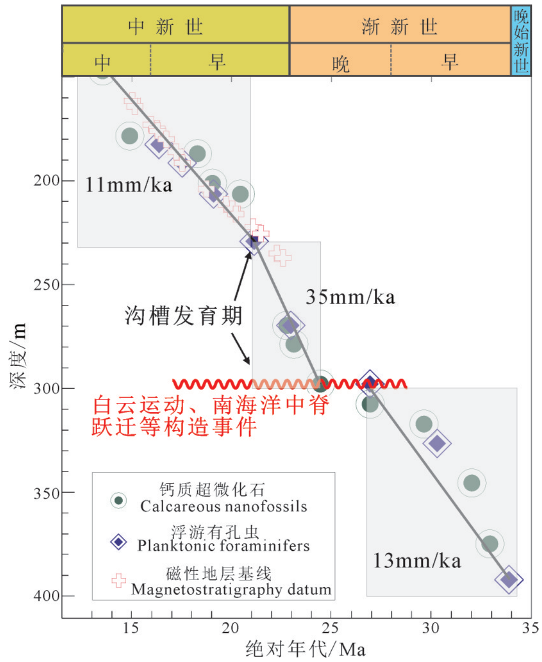

图9 研究区东南部大洋钻探U1501井揭示的沉积速率特征(据Larsen et al., 2018修改)

注:图中深度基准面为海底,自海底向下正记数

Fig.9 Sedimentary rate revealed by well IODP U1501 in the study area (modified from Larsen et al., 2018)

The reference datum is seabed and positive count from the reference datum

定量的方法对盆内局部物源的判断具有重要的指示意义。

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