

化学风化指数和磁化率对洞庭盆地 第四纪古气候变化的响应

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摘要:在安乡凹陷东南部两护村新施工揭穿第四系的ZKC1孔,孔内第四系为河流和湖泊沉积,地层组成自下而上依次为上新世—早更新世华田组、早更新世汨罗组、中更新世早期—中期洞庭湖组、晚更新世坡头组以及全新统等。对钻孔岩心进行了系统的主量元素及磁化率分析,进而从陆相沉积物化学风化指数(CWI)与温度和湿度正相关、磁化率与温度和湿度负相关的理论出发,探讨洞庭盆地第四纪气候演变。结合其他资料,CWI曲线特征指示洞庭盆地第四纪气候演变过程:早更新世为冷干→暖湿→冷干→暖湿,中更新世为冷干→暖湿→冷干—温湿→暖湿,晚更新世为寒冷→温湿→寒冷,全新世总体为温湿—暖湿。这一结论与ZKC1孔孢粉组合特征反映的气候演变过程及中国东部第四纪气候演化基本吻合,说明沉积物CWI对第四纪气候演变具有较好的响应。变化曲线及相关系数(-0.32)表明磁化率值与CWI值呈较明显的负相关,暗示温度和湿度对磁化率具有明显的控制作用。但可能受盆地升降等因素的影响叠加,磁化率曲线未能如CWI一样明确反映出第四纪气候的阶段变化。

关键词:化学风化指数;磁化率;第四纪;气候演变;洞庭盆地

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洞庭盆地在晚三叠世—侏罗纪陆内南北向挤压造山^[1]基础上,经白垩纪—古近纪伸展断陷^[2]和第四纪早期断陷、晚期拗陷而形成^[3-6]。关于洞庭盆地第四纪地质的研究由来已久,其中盆地第四纪气候演化是主要内容之一,不同研究者对其认识存在一定差异。如景存义^[7]提出早更新世气候先后为冷湿和暖湿,中更新世早期为冷湿、晚期为暖湿,晚更新世凉干,全新世早期温湿、中期暖湿、晚期温湿;蔡述明等^[8]认为早更新世早期湿热并向干冷变化、晚期为温性气候,中更新世早期寒温、晚期逐渐变暖,晚更新世逐渐由温暖趋向湿热,晚更新世晚期至全新世由暖性逐渐趋向湿热;杨达源等^[9]研究提出早更新世早期温湿、晚期凉湿,中更新世早期偏凉、晚期湿热,晚更新世早期温和、晚期冷偏湿,全新世总体为暖湿。上述各家关于洞庭盆地第四纪气候变化期划

分的差异,可能与地层划分不统一以及孢粉保存程度差异有关^[10]。张人权等^[11]基于各家认识,认为洞庭湖区更新世气候组合为暖湿(温湿)与冷干,且变化剧烈;全新世气候转为温凉,主要气候组合为温湿与凉干。

由于化学风化指数(CWI)与气温和湿度密切相关,因此近些年来被广泛用于古气候研究^[12-17]。已有研究表明,沉积物磁化率变化可以反映沉积时期的古气候变化,因此沉积物磁化率曲线被认为是一个较好的第四纪气候替代指标^[18-24]。近年来笔者在位于洞庭盆地中南部的汉寿县偏坡镇两护村施工了一个第四纪综合研究钻孔(ZKC1孔),并进行了系统的孢粉^[25]、地球化学、重矿物^[26]、粒度、磁化率、沉积年龄^[27]等样品的分析和研究。本文即探讨该孔沉积物化学风化指数和磁化率变化曲线的气候意义,

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以为区域第四纪气候演变研究补充新的资料。

1 区域地质背景

第四纪洞庭盆地西、南、东三面分别为武陵隆起、雪峰隆起和幕阜山隆起;北为江汉盆地,二者在西段相接,东段以华容(次级)隆起相隔(图1)。洞庭盆地由多个次级隆起和凹陷组成(图1)。隆起区多为低山丘陵与岗状平原,第四纪期间以抬升为主,因此多为基岩裸露,第四系厚度较小并组成多级阶地。凹陷区多为波状与低平原,第四纪期间有较大幅度沉降,不同时代沉积上下叠置,沉积厚度较大。上述隆-凹构造格局主要受第四纪正断裂控制(图1)。

两护村孔(ZKC1孔)位于安乡凹陷的东南部、赤山隆起的西侧(图1)。孔中晚新生代沉积总厚294.26 m,下伏地层为新元古代马底驿组。ZKC1孔晚近堆积自下而上划分为上新世—早更新世华田组(NQ_{ht}),早更新世汨罗组(Qp_{1m}),中更新世洞庭湖组(Qp_{2d}),晚更新世坡头组(Qp_{3p}),全新世湖冲积(Qh^{ml})等5个地层单位(图2),地层时代获得了ESR、OSL年龄数据^[25,27]及孢粉—气候资料^[25]的支撑。

华田组可分为上、下两段。下段下部为一套砾石层、砂砾层,中、上部总体为一套杂色粘土夹粉砂层。上段由砂—粉砂—(含粉砂质)杂色粘土组成4个下粗上细的韵律。汨罗组主要为一套细—粗砂层、含砾砂层夹(含)粉砂质粘土、粘土,下部少量砂砾石层。洞庭湖组可分为三段,下段为一套砂砾层、砾石层,上部夹少量偶含砾的粘土层;中段由砾石层、砂砾层、不等粒砂层、砂质粘土、粉砂质粘土、泥炭层等组成;上段为粘土、粉砂质粘土、粉砂层、泥炭层、瘀泥层,夹少量砂砾层。坡头组主体为一套土黄、褐黄、灰黄、浅黄色粘土,结构致密,多含较多铁锰质结核。全新统主要为粘土,少量粉砂和粉砂质粘土。上述堆积形成于河流和湖泊环境。

需要指出的是,洞庭盆地在晚更新世晚期发生过一定幅度的整体抬升并遭受剥蚀^[3-6,27-31],因此ZKC1孔中洞庭湖组形成于中更新世早期和中期,中更新世晚期缺失沉积。

2 样品采集与分析

取自ZKC1孔岩心中的地球化学分析样品共311件,主要岩性为粘土、粉砂质粘土及粘土质粉砂,少部分为砂层;取样间距0.5~1 m(不包括砂砾

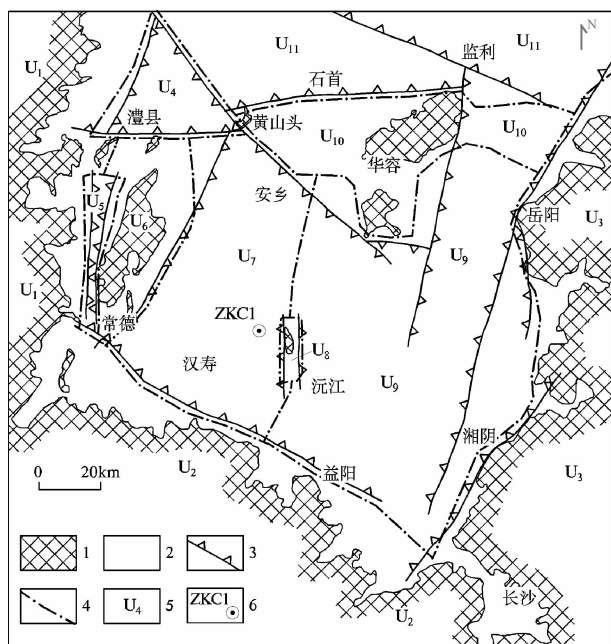


图1 第四纪洞庭盆地构造格局

1—前第四纪地层出露区;2—第四纪地层出露区;3—第四纪正断裂,齿向示下降盘;4—构造单元分界线;5—构造单元代号;6—两护村ZKC1孔位置。构造单元名称:U₁—武陵隆起;U₂—雪峰隆起;U₃—幕阜山隆起;U₄—澧县凹陷;U₅—临澧凹陷;U₆—太阳山隆起;U₇—安乡凹陷;U₈—赤山隆起;U₉—沅江凹陷;U₁₀—华容隆起;U₁₁—江汉盆地

Fig.1 Tectonic framework of Quaternary Dongting basin
1—Outcropped area of pre-Quaternary strata; 2—Outcropped area of Quaternary strata; 3—Quaternary normal fault, time indicating downthrown block; 4—Boundary of tectonic unit; 5—Symbol of tectonic unit; 6—Location of ZKC1 borehole in Lianghucun. Name of tectonic unit: U₁—Wuling uplift; U₂—Xuefeng uplift; U₃—Mufushan uplift; U₄—Lixian depression; U₅—Linlin depression; U₆—Taiyangshan uplift; U₇—Anxiang depression; U₈—Chishan uplift; U₉—Yuanjiang depression; U₁₀—Huarong uplift; U₁₁—Jianghan basin

层段)。未进行粒度分离,均为全样分析。样品送国土资源部长沙矿产资源监督检测中心进行SiO₂、Al₂O₃、TFe₂O₃、FeO、MgO、CaO、K₂O、Na₂O、TiO₂、MnO等共10项主量元素(氧化物)分析。样品用KOH熔融, SiO₂采用重量法测定,分离SiO₂之后的滤液用ICP—等离子发射光电直读光谱仪(全谱仪)测定组分含量。

磁化率分析样品共361件,取样间距0.5~0.8 m(不包括砂砾层段)。磁化率测量在中国地质大学(武汉)地球物理与空间信息学院实验室的HKB-3型卡帕桥上完成,测量精度 $\leq 2 \times 10^{-8} \text{SI}$ 。对每一件样品重复测量2次,取其均值作为最后的结果。

顺便指出,地球化学和磁化率样品一般于对应

位置采取,但考虑分析成本前者样品有抽稀,因此两者取样间距有所差异。

3 化学风化指数和磁化率曲线特征及其气候意义

一般而言,表壳岩石的风化造成含 Na、K、Ca 的硅酸盐被淋滤,并被新发育的富 Al 粘土矿物取代,风化产物中的 Al_2O_3 与 $CaO+Na_2O+K_2O$ 的比值相应增加。风化程度可以化学风化指数(即 CWI, 计算式为 $[(Al_2O_3)/(Al_2O_3+CaO+K_2O+Na_2O)] \times 100$ (分子数)^[32])定量表示。通常气温越高、湿度越大越有利于岩石风化,因此风化沉积产物化学风化指数值的高、低一般分别对应于温暖湿润和寒冷干燥的气候条件。

磁性矿物在各种环境中的运动和转化中充当了环境信息的重要载体,一定条件下可指示环境和气候的变化^[33]。就陆相盆地而言,长期的滞水和还原环境可以使磁铁矿转化为弱磁性矿物^[34],从而降低沉积物的磁化率;冷干期降水量少,使洼地水体浅或出露为滩地而处于氧化环境,沉积物磁化率值一般因此偏高^[19,20]。可见,通常气候越寒冷、干燥则沉积物磁化率值越高^[23]。这与化学风化指数值随气候的湿热程度增加而增高正好相反,故理论上 CWI 与磁化率之间一般应呈负相关。

两护村孔岩心的 CWI 和磁化率曲线如图 2 所示(为便于作图,在不影响阶段性气候变化特征分析的前提下,磁化率的个别奇异值(极高值)未投影在图中)。其中 CWI 曲线从下而上(从早至晚)呈现出明显的波状起伏,反映出研究区第四纪古气候呈现出暖湿与冷干的交替变化。

从 CWI 值一般与气候暖湿度正相关出发,图 2 中地球化学曲线大致反映自下而上不同层位沉积对应气候信息:上新世—早更新世华田组下段所对应的气候暖湿,华田组上段下部对应气候冷干,华田组上段上部对应气候暖湿;早更新世汨罗组下部对应气候冷干,汨罗组上部对应气候暖湿;中更新世洞庭湖组中部对应气候暖湿(下部砂砾层无样品),上部对应气候冷干—温湿;晚更新世坡头组对应气候温湿;全新世湖冲积对应气候变化较复杂,总体温湿—暖湿。

以上是基于钻孔地层层位及取样所进行的分时期气候分析,尚不能代表从早至晚连续的气候演变

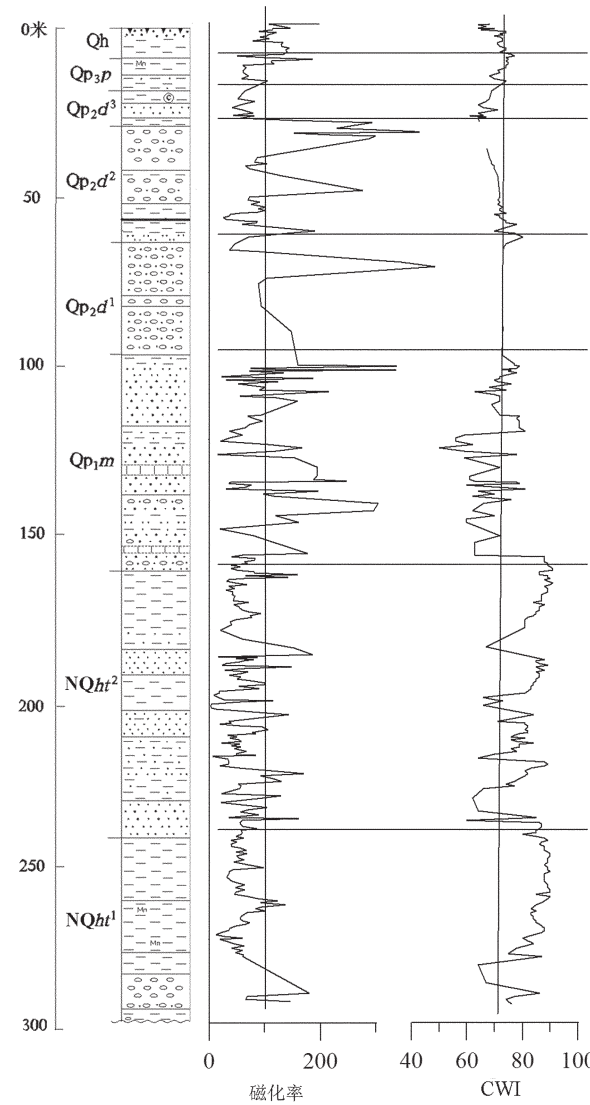


图 2 ZKC1 孔磁化率(10-6 SI)和化学风化指数(CWI)曲线
NQht¹—上新世—早更新世华田组下段;NQht²—华田组上段;
Qp_{1m}—早更新世汨罗组;Qp_{2d}¹—中更新世洞庭湖组下段;
Qp_{2d}²—洞庭湖组中段;Qp_{2d}³—洞庭湖组上段;
Qp_{3p}—晚更新世坡头组;Qh—全新统

Fig.2 Curves of magnetic susceptibility (10-6 SI) and chemical weathering index (CWI) variation of ZKC1 borehole
NQht¹—Lower part of Pliocene-Early Pleistocene Huatian Formation;
NQht²—Upper part of Huatian Formation; Qp_{1m}—Early Pleistocene Miluo Formation; Qp_{2d}¹—1st part of Middle Pleistocene Dongtinghu Formation; Qp_{2d}²—2nd part of Dongtinghu Formation;
Qp_{2d}³—3rd part of Dongtinghu Formation;
Qp_{3p}—Late Pleistocene Potou Formation; Qh—Holocene

过程。如考虑到洞庭湖组下部(下段)大套砂砾层(干冷气候下的低水位沉积^[25])无样品控制;中更新世晚期因构造抬升缺失沉积^[25-27],且先期沉积粘土受湿

热化作用而形成网纹红土^[3-6,27-31];晚更新世早期洞庭盆地仍缺乏沉积;晚更新世末区域海(湖)平面下降导致沉积缺失^[25,26]等气候信息记录不连续因素,结合其他区域气候演化背景资料^[35],则可据 CWI 曲线特征恢复洞庭盆地第四纪期间气候演变过程(表 1);早更新世为冷干→暖湿→冷干→暖湿,中更新世为冷干→暖湿→冷干—温湿→暖湿,晚更新世为寒冷→温湿→寒冷,全新世总体为温湿—暖湿。这一结论与 ZKC1 孔孢粉组合特征反映的气候演变过程^[25]基本吻合,也与杨怀仁等^[35]关于中国东部第四纪气候演化的认识一致(表 1),说明孔中沉积物的 CWI 明显受气候变化控制,可以指示第四纪气候演变过程。

相对 CWI 曲线而言,磁化率值的变化更为频繁、剧烈,且未如 CWI 一样显示出较大时间尺度的起伏(图 2)。但从相邻样品分析值的高低变化趋势来看,磁化率与 CWI 值同理论上一样总体表现出较明显的负相关,即前者显示的谷、峰大多分别对应于后者的峰、谷。通过 SPSS 软件对磁化率和 CWI 取样位置相同(对应)样品进行相关分析,得到其相

关系数为-0.32^①,与曲线反映的信息一致。鉴上,可初步推断气候冷暖和干湿变化对磁化率确实具有明显的控制作用,但受其他因素叠加影响而未能明确反映出第四纪气候的阶段性的变化。事实上,除气候因素外,沉积物供给速率和盆地升降变化也可引起水位变化,从而明显影响到沉积物的磁化率值^[20]。对 ZKC1 孔岩心进行的重矿物分析和砾石统计分析表明,洞庭盆地上新世末至中更新世中期的沉降具有明显的幕式特征^[26]。因此,盆地构造活动很可能是造成 ZKC 孔磁化率曲线对第四纪古气候变化指示不明显的重要因素之一。

值得指出的是,尽管磁化率未独立反映出第四纪气候演变过程,但其与 CWI 之间较为明显的负相关性与气候环境对 CWI 和磁化率控制作用的理论相吻合,以此印证了 CWI 所反映的气候演变过程。从此意义上讲,磁化率对洞庭盆地第四纪气候演变仍有响应。

综上述,两护村 ZKC1 孔沉积物的 CWI 和磁化率均受气候变化控制,其中 CWI 值明确反映了第四纪气候演变,而磁化率因尚受其他因素控制而

表 1 两护村 ZKC1 孔岩心化学风化指数(CWI)反映的第四纪古气候信息
Table 1 Quaternary palaeoclimatic variations indicated by chemical weathering index (CWI) of Lianghucun ZKC1 borehole

时 代		层 位	CWI 反映气候 信息	孢粉反映气候 信息(孢粉带) ^[25]	杨怀仁等 ^[35]
全新世		全新统湖冲积	复杂, 总体温湿 —暖湿	暖稍干(XVI) 暖稍湿(XV)	冷干→温干→暖湿→ 温干→凉湿
晚更 新世	晚期	(缺失沉积)	(寒冷)	(寒冷)	严寒偏干
	中期	坡头组	温湿	温较湿(XIV)	湿温
	早期	(缺失沉积)	(寒冷)	(寒冷)	寒冷
中更 新世	晚期	(缺失沉积)	(暖湿)	(湿热化或网纹化)	
	中期	洞庭湖组上部	冷干—温湿	暖稍湿(XIII)	湿热
		洞庭湖组中部	暖湿		
早更 新世	早期	洞庭湖组下部	(无样品, 冷干)	(无样品, 冷干与低水位)	寒冷
	晚期	汨罗组上部	暖湿	暖较湿(XI, XII)	湿暖
		汨罗组下部	冷干	较冷干间温湿(VIII~X)	冷
上新世	早期	华田组上段中、上部	暖湿	暖湿间凉干(V~VII)	温暖
		华田组上段下部	冷干	凉干(III, IV)	冷
上新世	末期	华田组下段	暖湿	暖干(I, II)	暖干

注:孢粉带划分及特征见文献[25]。

① 柏道远.洞庭盆地第四纪地质环境演化(博士论文).武汉:中国地质大学,2010.

对气候阶段性指示不明显。

4 结 论

(1)两护村 ZKC1 孔岩心 CWI 曲线特征指示洞庭盆地第四纪气候演变过程:早更新世为冷干→暖湿→冷干→暖湿,中更新世为冷干→暖湿→冷干→温湿→暖湿,晚更新世为寒冷→温湿→寒冷,全新世总体为温湿→暖湿。这与 ZKC1 孔孢粉组合特征反映的气候演变过程及中国东部第四纪气候演化基本吻合。

(2)磁化率明显受到温度和湿度控制,但可能受盆地升降等因素的影响叠加而未能明确反映出洞庭盆地第四纪气候的阶段性变化。

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Chemical weathering index and magnetic susceptibility of deposits and their responses to the Quaternary climate in Dongting Basin

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Abstract: The drilling of ZKC1 borehole was carried out at Lianghucun in southeastern Anxiang sag. The Quaternary alluvial and lacustrine sediments in the borehole are composed of Pliocene-Early Pleistocene Huatian Formation, Early Pleistocene Miluo Formation, early-middle Middle Pleistocene Dongtinghu Formation, Late Pleistocene Potou Formation and Holocene strata. The major elements and magnetic susceptibility of the core from the borehole were analyzed systematically. According to the idea that the chemical weathering index (CWI) of terrestrial sediments has a positive correlation with temperature and humidity, and that the magnetic susceptibility has a negative correlation with temperature and humidity, the authors probed into the Quaternary climate evolution of the Dongting basin. Combined with other materials, the curve of CIA indicates that the Quaternary climatic evolution of the Dongting basin was from early to late in order of cool and dry → tropical and humid → cool and dry → tropical and humid during Early Pleistocene; cool and dry → tropical and humid → cool and dry-warm and humid → tropical and humid during Middle Pleistocene; cool → warm and humid → cool during Late Pleistocene, and warm and humid-tropical and humid during Holocene. This climatic evolution process coincides basically with climatic change indicated by sporopollen assemblages of the core from the ZKC1 borehole, and also accords with Quaternary climatic variations of eastern China, which suggests that the CWI of the sediments shows a good responses to the Quaternary climate evolution. Curves and correlation coefficient of -0.32 between CWI and magnetic susceptibility of the sediments show that the magnetic susceptibility has a negative correlation with CWI, which suggests that temperature and humidity controlled evidently the magnetic susceptibility. Impacted probably by the uplift and subsidence of the basin, the curve of the magnetic susceptibility fails to show the same phasic variations as CWI.

Key words: chemical weathering index; magnetic susceptibility; Quaternary; climatic evolution; Dongting Basin

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