

阿尔金新近纪红黏土粒度特征及古气候记录

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摘要 为反演阿尔金新近纪红黏土记录的古气候、古环境信息,在已有的磁性地层学约束基础之上对剖面的粒度指标进行了系统的分析,并利用粒度端元模型(EMM)进行分解。结果表明,可分为三个粒度端元:端元1(众数粒径 5.2 μm)众数粒径集中分布于 2~6 μm ,与北太平洋西风带粒度分布和中国黄土细粒组分的粒度分布相似;端元2(众数粒径 20 μm)呈负偏态非对称分布,众数粒径在 32~16 μm 之间,为低空西风所搬运短距离做跃移运动的粉尘物质;端元3为双主峰分布,众数粒径 57 μm 和 2.5 μm ,代表着尘暴事件中风动力近源变化强度,反映混合沉积特征。其中在 10.8~10.3 Ma、8~6 Ma、5.2~4.3 Ma、3.6~2.8 Ma 端元1 粒度含量呈减小趋势,端元2 粒度百分含量呈逐渐增加趋势,中值粒径增大。13~2.6 Ma 阿尔金红黏土记录显示内陆干旱化加剧事件经历了 10.8~10.3 Ma、8~6 Ma、5.2~4.3 Ma、3.6~2.8 Ma 四个阶段,结合前人对该剖面及邻区其他地质环境记录研究表明,亚洲内陆干旱化可能的起始时间为 11 Ma 左右,西风环流在本区占主导地位。全球变冷是内陆干旱化加剧的主导要素,青藏高原的阶段性隆升起着推动作用。

关键词 阿尔金;红黏土;粒度;新近纪;端元模型;西风

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0 引言

黄土高原及周缘地区广泛分布的黄土—古土壤序列及下伏红黏土是反演古环境、古气候演化的良好载体。经数十年研究,基于磁性地层学的磁化率^[1-5]、粒度^[6-9]的精细研究,重建了晚新生代以来的气候演化过程,并识别出 14~10 Ma^[10]、8 Ma^[11-14]、3.6 Ma^[15]及 2.5 Ma^[16-17]等若干重要气候事件。粒度是风成堆积的基本物理特性,是研究古气候信息的重要指标。对于黄土、红黏土等风成堆积物来说,不同的粒度特征和粒度参数受控于物源或气候搬运模式,这是粒度用于反演古气候演化的前提与基础。Pye *et al.*^[18] 研究显示风力的搬运方式分为悬移、跃移和蠕移三种状态,分别代表三种不同的沉积动力,与三种粒径相对应。研究表明,风成堆积物也并非单一动力作用产物的事实,基于不同数学和动力学模型的粒度端元分解运用而生,并得到广泛应用^[19]。黄土高原的粒度主要反映了季风和高空西风的特征,Sun *et al.*^[20] 认为自 23 Ma 以来,现今的古气候格局已经形

成,西部主要受控于西风,Pan *et al.*^[21] 也证实了这一观点。目前对反演低空西风演化研究程度较低。近年来,对于红黏土的研究不仅仅局限于黄土高原地区,在中国西部准噶尔盆地、阿尔金地区也陆续发现风成堆积—红黏土^[20,22]。位于西风区的阿尔金山彩虹沟剖面在古生物化石的约束之下已完成了磁性地层年代学,建立了 13~2.6 Ma 年代地层序列,时代为新近纪中中新世至上新世^[22-23]。通过对阿尔金新近纪红黏土磁化率研究表明,初步重建了西风区中新世晚期—上新世以来的气候演化过程,并识别出了 12 Ma 的干旱化增强事件^[23]。这为中国西部地区区域古气候研究提供了重要资料。但是目前关于西风区详细的古气候信息研究仍不足,为了更好地提取古气候和古环境记录,本文利用阿尔金山新近纪红黏土进行粒度端元模型分析反演,进一步讨论新近纪以来阿尔金地区的古气候演化历史。

1 研究区概况

研究剖面位于青藏高原北缘阿尔金山索尔库里

盆地一带,北邻塔里木盆地,南接柴达木盆地^[24](图1)。根据前人完成的1:25万巴什库尔干幅区域地质调查^[25]可知,索尔库里北盆地的新生代地层划分为始新世溪水沟组(N_x)、新近纪彩虹沟组(NQ_c)、早—中更新世七个泉组(Q_q)、上更新统及全新统。而新近纪红黏土剖面位于索尔库里北盆地东部彩虹沟,彩虹沟剖面总厚度为94.2 m,上部为5.8 m的薄层状泥岩,下部为88.4 m的红黏土及钙质结核交互组成,自上而下可见40个厚度不同的旋回,其成壤作用较弱,铁锰胶膜稀疏分布^[23]。根据颜色及红黏土与钙质结核的比例可将其分为两个部分:上部主要以红褐色黏土夹棕黄色钙质结核层为主(二者比例约为8:1~10:1),部分钙板层在走向上尖灭;下部主要由黄棕色黏土和灰色钙质结核层组成(4:1~5:1)^[23]。已经完成磁性地层学测试,同期采集的粒度分析样品为20 cm间距采取。

2 研究方法

2.1 样品处理与测试

所有粒度样品在西北大学大陆动力学国家重点

实验室完成。测试仪器为英国MALVERN仪器公司生产的Mastersizer 2000型激光粒度仪,测量范围为0.02~2 000 μm,重复测量误差小于2%。红黏土样品在上机测试之前需进行详细的前处理。步骤如下:1)称取适量的粉末样品,放入100 mL的烧杯中;2)加入10%的双氧水(H₂O₂) 10 mL,放置在加热板上加热至完全反应,主要目的是去除样品中的有机质;3)待烧杯温度冷却后,再加入10%盐酸(HCl) 10 mL,摇匀后在加热板上加热煮沸使之反应充分,以除去样品中的碳酸盐物质;4)给反应后的烧杯中加满蒸馏水,静置12 h以上,用吸管去除上部蒸馏水;5)最后在烧杯中加入10%分散剂(NaPO₃)₆ 10 mL,将其放置于超声波分散仪中震动10 min,使其充分分散成最佳溶液,然后上机测量,最终得出粒度的各项指标。

2.2 粒度分析方法

端元模型分析法最早由Weltje^[26]提出认为,沉积物粒度分布由不同沉积动力决定。近年来,应用粒度端元模型算法(End-Member Modeling algorithm)^[27]进行各个粒度组分的分解,该方法已被证明在分解具有复杂物源或沉积过程风成堆积的粒度端元方面效

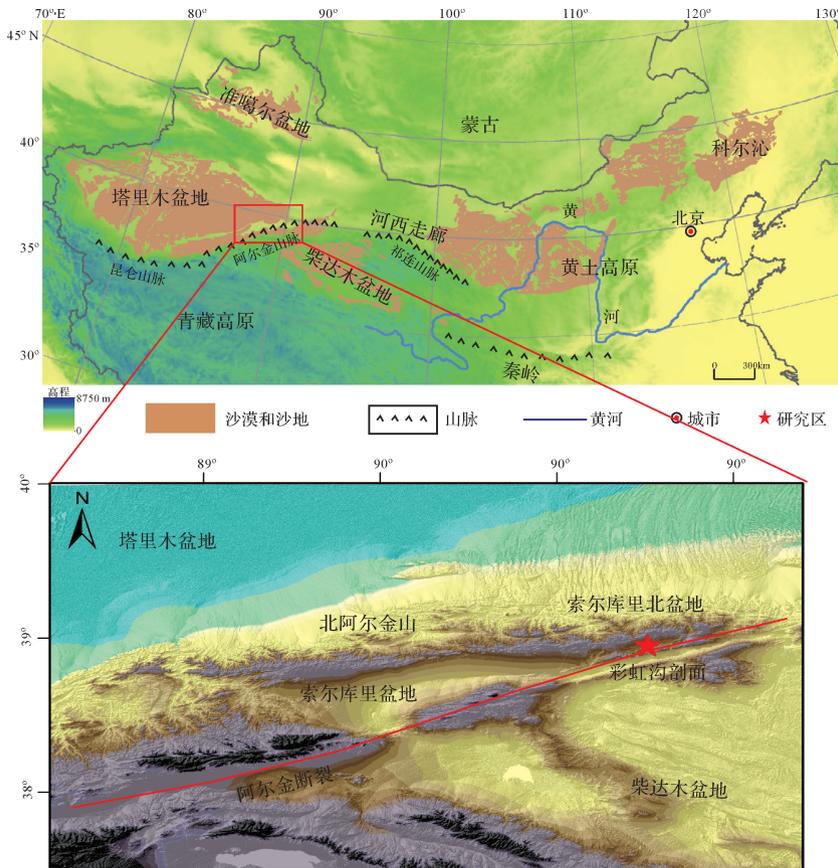


图1 研究区及邻区概况图

Fig.1 Tectonic map of the study area and adjacent regions

果突出^[24,28],然后分别讨论分解所得的各个端元组分所代表的古气候演化过程。本次利用 Paterson *et al.*^[29]基于端元分析模型(End-Member Modeling)利用 Matlab 平台开发的程序 AnalySize 对彩虹沟红黏土粒度 433 个样品数据进行端元分析。

3 端元分析结果

对彩虹沟粒度数据计算结果(图 2a)显示,它们的复相关系数(R^2)分别为 0.82、0.95、0.97、0.98、0.99。从对数据拟合的程度来看,粒度端元数为 2 时,拟合程度较好,能较好地代表粒度数据的总体特征,因此本文将选取 3 个端元对粒度数据进行分析。

根据拟合的粒度端元频率分析(图 2b),EM1、EM2 呈单峰分布,接近正态分布,分选较好。EM2 除主峰外还存在一个次峰。而 EM3 具有两个峰值,细颗粒的峰值和 EM1 粒度范围相似。端元 1 的峰值主要集中在 1~10 μm ,端元 2 的峰值主要集中在 10~100 μm ,端元 3 的峰值集中在 1~10 μm 和大于 100 μm 。根据图 2b 和粒度的百分含量可知,EM1 的众数粒径为 5.2 μm ,粒度百分含量在 0~97.3%,平均值为 47.9%,属于极细粉砂;EM2 的众数粒径为 20 μm ,粒度百分含量在 0~82.8%之间,平均值为 35%,属于中粉砂,除主峰外,还存在一个次峰众数粒径为 1.7 μm 属于黏土;另外,EM3 的众数粒径 57 μm 属粗粉砂,另一个主峰的众数粒径为 2.8 μm ,平均百分含量低为 17%。

4 讨论

4.1 各端元的环境意义

已有研究表明,石英颗粒表面微结构特征可分析讨论沉积物的沉积环境、恢复古环境、确定古沉积相及其演变过程^[30]。风成黄土主要是大气悬移状态的粉尘堆积,石英颗粒之间接触碰撞机会较少,因此,黄土中石英颗粒棱角多数较尖锐。前人通过对彩虹沟红黏土石英颗粒微形态的研究发现,几乎所有的石英颗粒有着棱角状和次棱角状的外形,大部分都呈现非常典型的刃状和贝壳状断口,也可见到碟状坑(图 3c)^[22-23],说明粉尘颗粒在从远处搬运过程中受到机械作用而产生痕迹。X 衍射分析表明阿尔金新近纪红黏土主要由石英、长石、伊利石、伊蒙混层、白云石及少量高岭石和绿泥石组成,与黄土高原石楼红黏土较为一致(图 3d)^[23]。洛川红黏土岩石地球化学(氧化物)分析结果与阿尔金红黏土平均值比值相比,直线斜率近于 1,指示二者相似的地球化学组成(图 3e, f)^[23]。阿尔金红黏土稀土配分曲线以富集轻稀土元素和具有明显的铈异常为特征,也与洛川风成堆积相似(图 3g)^[23]。

从新近纪红黏土的粒度频率曲线可见,粒度分布大部分呈双峰分布,主峰位于 10~40 μm 之间。次峰分布的粒度范围较大,有的位于 2 μm 左右,个别的较粗,次峰位于 30 μm 左右(图 4)。个别曲线偏向粗颗粒,曲线呈现出不对称,在细颗粒一端呈现出长尾巴状,和黄土高原的黄土粒度频率分布曲线相似。粒

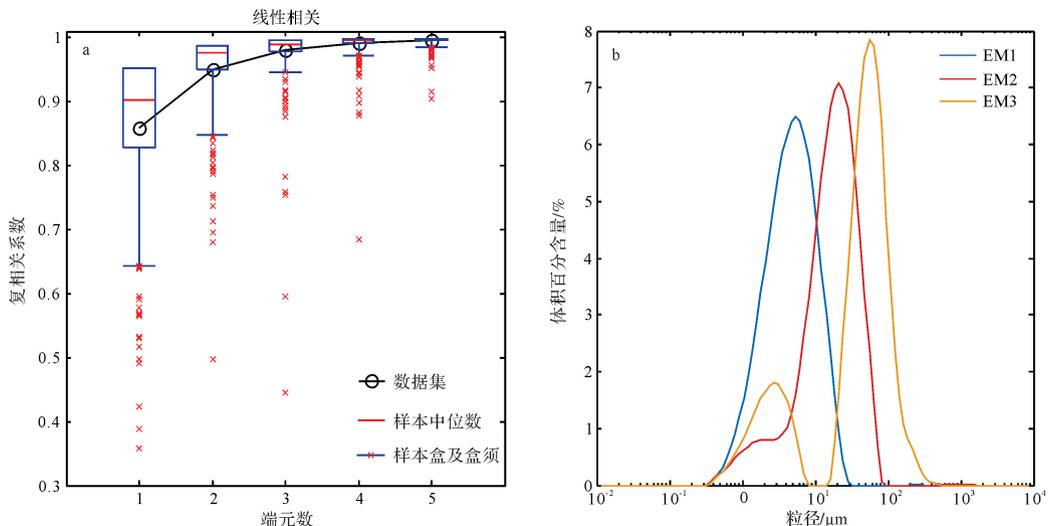


图 2 三个粒度端元频率分布图

Fig.2 Sediment particle size analysis using the End-Member model

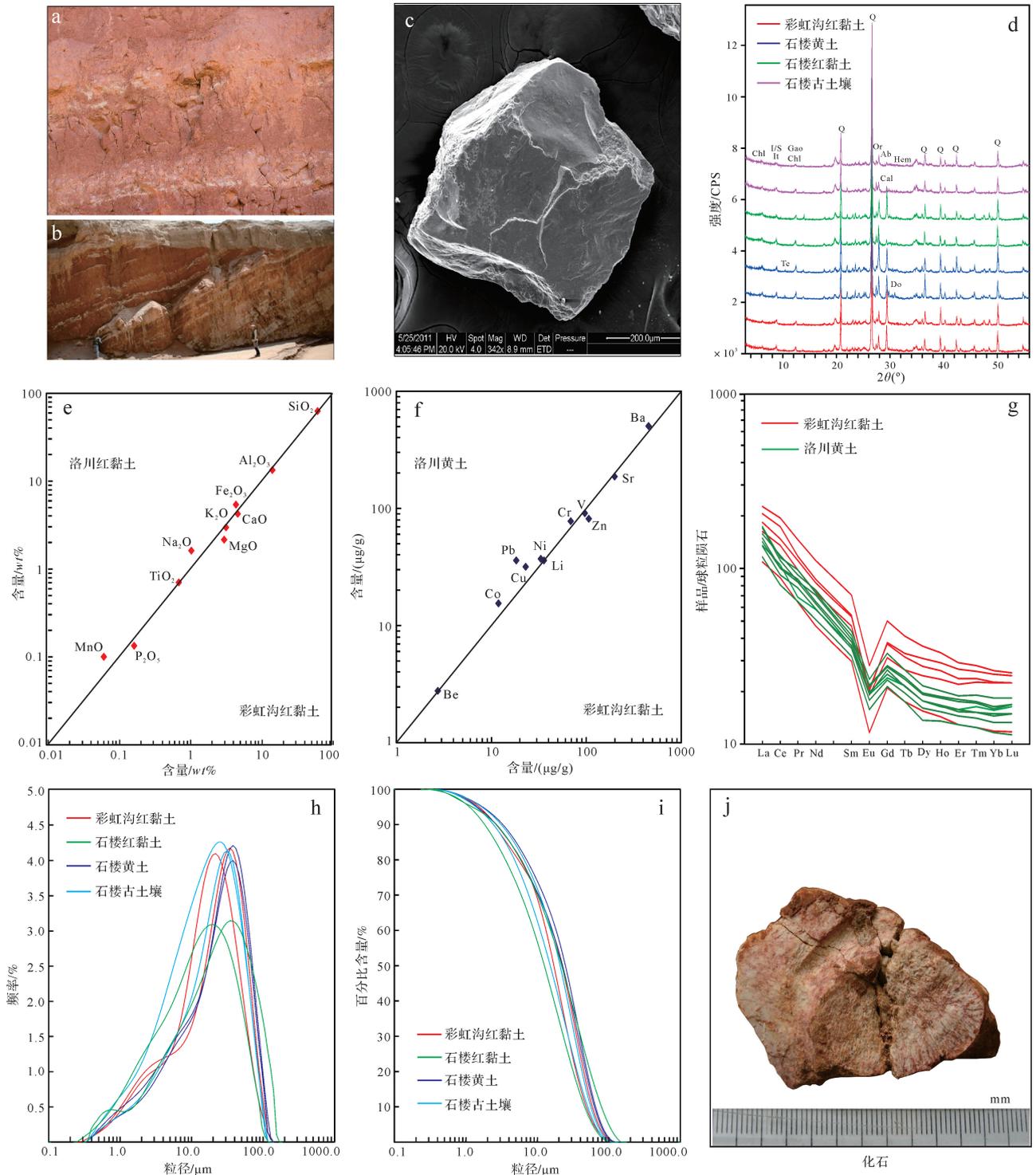


图3 阿尔金彩虹沟剖面红黏土沉积证据

Fig.3 Altun Red clay depositional evidence

度分布由 $0.3\sim 0.5\ \mu\text{m}$ 至 $40\sim 100\ \mu\text{m}$ 分布,但集中在 $3\sim 50\ \mu\text{m}$,和黄土高原红黏土分布曲线相似。新近纪红黏土粒度分布和黄土高原稍有区别,黄土高原红黏土上部在 $0.3\sim 1\ \mu\text{m}$ 粒度出现一个小的峰值,这些超

细的颗粒主要由成土过程中胶体或者可溶物质组成。彩虹沟粒度频率分布曲线呈现出双峰分布,粒径集中在 $3\sim 50\ \mu\text{m}$,粒度的分布范围和分布形态和黄土高原的黄土—红黏土非常相似,属于典型风成物质的分

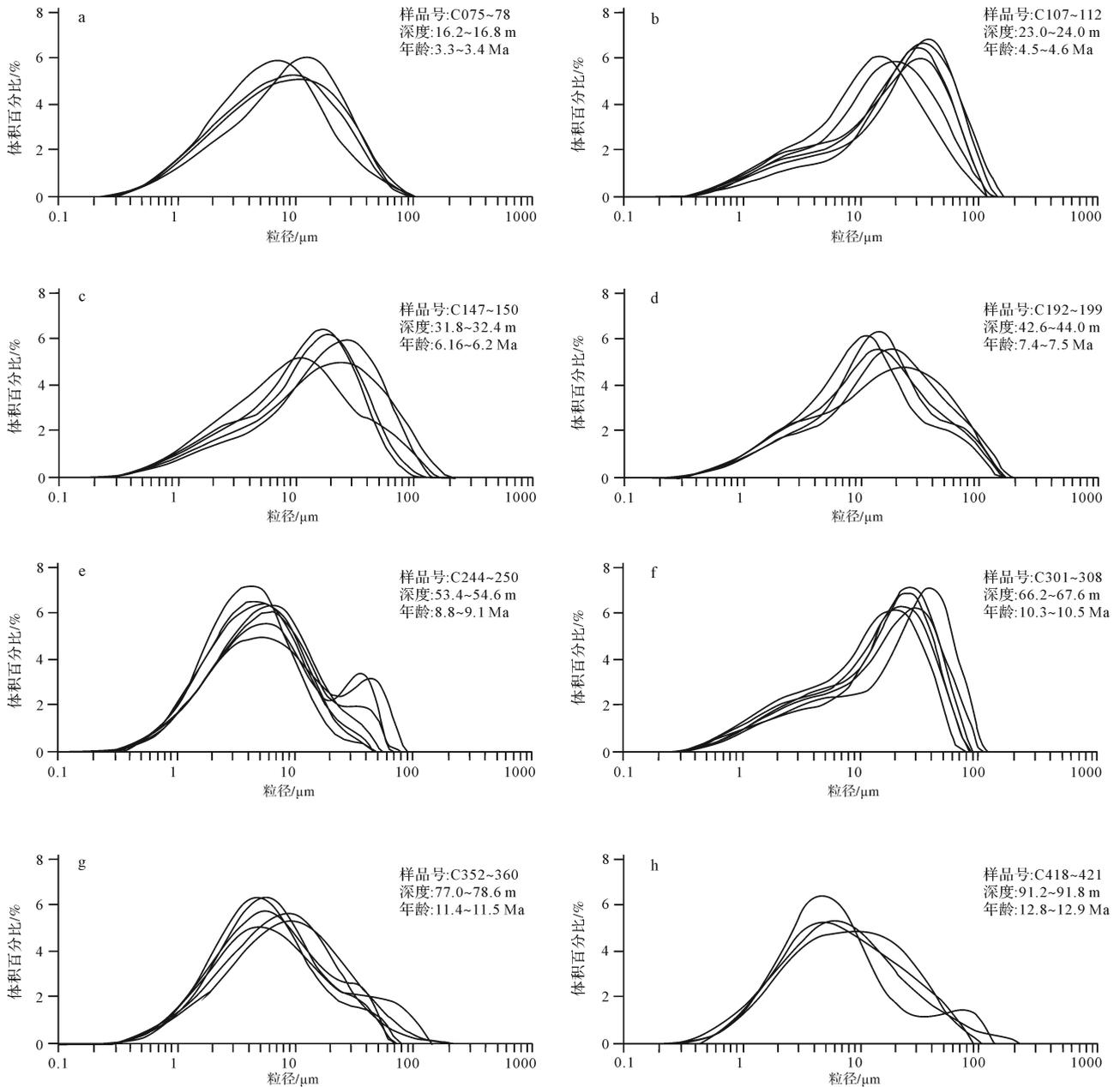


图4 彩虹沟粒度频率曲线

Fig.4 Particle-size frequency distribution curves

布形态(3h,i)。

中国风尘沉积的粒度分布由粗粒组分和细粒组分组成,粗粒组分代表的是近距离低空搬运的粉尘物质,指示了粉尘源区和沉积区的干燥度;细粒组分可能代表的是高空西风气流搬运的远源粉尘,指示了西风带控制的高空气流强度^[8]。

从端元1的频率分布曲线上看(图2b),端元1与北太平洋西风带粉尘粒度分布^[31]和中国黄土的细粒组分的粒度分布^[8]具有一致性,众数粒径在2~6 μm 之间,EM1细粒(众数粒径5.2 μm)粒度频率分布与榆

林L1细粒组分众数粒径4.2 μm 、西峰L1细粒组分众数粒径5.7 μm 、西峰红黏土细粒组分众数5.8 μm ^[8]粒度的分布特征相似。因此端元1可能代表的是高空西风控制下远源背景下做悬移运动的粉尘物质。

端元2与中国风成黄土的粗粒组分^[8]相似,呈负偏态非对称分布,众数粒径在32~16 μm 之间,EM2粗粒(众数粒径20 μm)与中国黄土西安L1粗粒组分21 μm 和旬邑L1粗粒组分27.8 μm ^[8]相似,但是东部的风成黄土粗粒组分主要受东亚季风影响较大。由于阿尔金山位于青藏高原北部西风区,中新世

晚期,青藏高原北部的周缘山脉均发生了强烈的剥蚀隆升,如祁连山脉海拔已达到 3 586 m^[32],阻碍了季风的运移通道,吹过来粉尘只能山前堆积,无法跨越高大山脉到达阿尔金地区,所以季风无法影响到阿尔金地区,因此端元 2 可能代表的是低空西风所搬运的短距离做跃移粉尘物质。

端元 3 为双主峰分布,众数粒径 57 μm 和 2.5 μm,与黄土双峰分布^[8]特征不同。Pye^[33]总结出了普通尘暴事件中的颗粒各粒级的组分占主导的搬运方式,搬运高度及搬运距离认为:砂与粉砂级粗粒(70~500 μm)每次只能上升至几米或几厘米高度,做跃移运动形成风成砂;中粗粉砂和细砂(20~70 μm)在大气几百米范围内做短距离悬移运动,风力降低时沉降下来形成了黄土的粗粒组分;细粉砂、极细粉砂和黏土(<20 μm)在上千公里的高空中做长距离的悬移运动沉降下来形成黄土中细粒组分。因此端元 3 可能代表的是尘暴事件中风动力近源的变化强度,另一个峰值与端元 1 近似,总体反映了混合沉积的特点。出现的细粒级(2.5 μm)的主峰,也可

能是细颗粒聚合体或者细颗粒附着在大颗粒上被强劲近地面风搬运^[34]。

综上端元 1 代表高空西风控制下远源背景下做悬移运动的粉尘物质;端元 2 代表低空西风所搬运的短距离做跃移粉尘物质;端元 3 代表了尘暴事件中风动力近源的变化强度,反映了混合沉积特点。通过粒度端元随年代变化曲线(图 5),10.8~10.2 Ma 以低空西风为主,粗颗粒百分含量增加;8.0~6.0 Ma 以近地表西风为主,在 8.0~6.0 Ma 也可能出现了尘暴事件混合沉积;5.2~4.3 Ma 粗粒组分缓慢增加,以低空西风为主;3.6~2.5 Ma 以低空西风为主。

4.2 阿尔金地区 13~2.6 Ma 古气候演化

10.8~10.2 Ma 在彩虹沟红黏土剖面,根据粒径的大小和含量的变化反映风动力的大小和气候的干湿变化。这一时期(图 5)端元 1(细粒组分众数粒径 5.2 μm)自 10.8 Ma 开始细粒含量明显减少,端元 2(粗粒组分众数粒径 20 μm)含量明显持续增加,10.37 Ma 左右端元 2 粗粒含量达到峰值(图 5),揭示了该时间段阿尔金地区干旱化程度持续增强,粗粒组

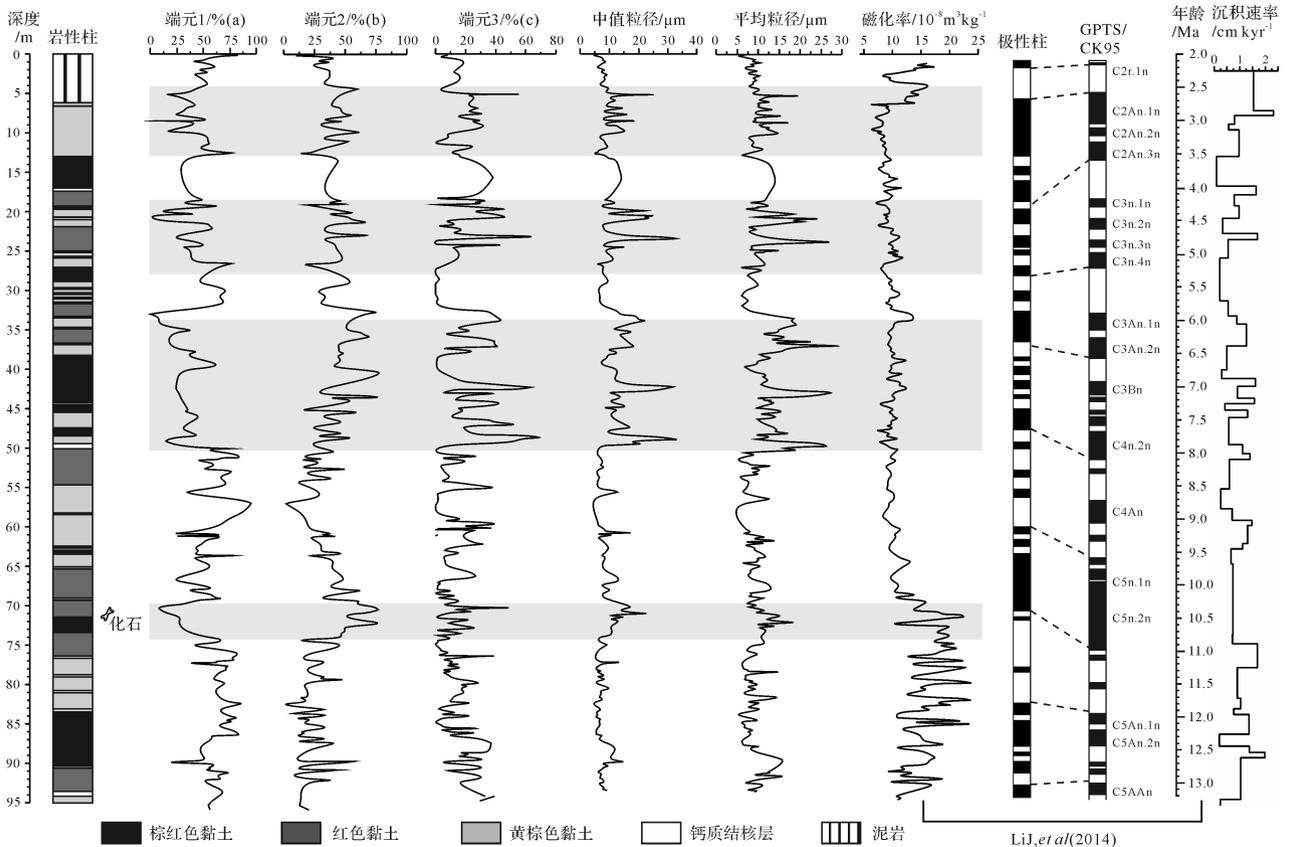


图 5 彩虹沟 3 个粒度端元随年代变化分布与彩虹沟剖面平均粒径和中值粒径数据对比

Fig.5 Various contributions Courtbtribution varititious of each End-Member versus age(a,b,c) and comparison with mean and median size content variatious(d,e) from the Caihonggou section

分的增加指示了近地表风力增强。中值粒径也呈逐渐增加趋势,变化介于6~23 μm ,平均值为11.3 μm 。在11.5~10.3 Ma 该剖面的磁化率^[23]突然下降,从 23.16×10^{-8} 到 $8.78 \times 10^{-8} \text{ m}^3/\text{kg}$ 与粗粒组分、中值粒径变化相对应(图5),指示了阿尔金地区干旱化出现。11 Ma 阿尔金红黏土的沉积速率增加主要是由于粗粒组分含量的增加所致,即具有较多的近源粉尘物质加入。因此,可以推测亚洲内陆干旱化可能始于11 Ma,阿尔金山周缘地区也出现类似事件,如在柴达木盆地中的沉积物记录中的碳氧同位素在12 Ma 发生了偏移^[35]和在盆地的西缘沉积物的地球化学指标在11 Ma 左右发生变化都被论证为亚洲内陆干旱化事件^[36]。临夏盆地沉积物记录中的碳氧同位素在13~11 Ma 前后发生一次大的正偏移被解释为干旱或高温气候事件^[37]。准葛尔盆地和塔里木盆地的碳氧同位素研究也有类似事件发生^[38-39]。相反,此时的黄土高原地区的古气候指标(粒度、磁化率等)较稳定指示该时期当地的气候变化不明显^[40-41]。

8.0~6.0 Ma 该段时期(图5)端元1(细粒组分众数粒径5.2 μm)呈突然减小趋势,端元2(粗粒组分众数粒径20 μm)整体呈逐渐增加的趋势(个别样品可能为异常值),端元3呈突然增大趋势,这可能暗示着该时期近距离低空风搬运的粉尘。中值粒径早已经被用于重建黄土高原冬季风的替代性指标^[42],同样也适用于红黏土之中。彩虹沟红黏土的中值粒径在8.0~6.0 Ma 明显的增大(图5),由于阿尔金处于西风区,因此中值粒径和粗粒组分的增大,可能指示的是低空风的增强和内陆干旱化显著加强。同期,6.0~8.0 Ma 中国东部黄土高原地区也出现大规模的风成红黏土堆积^[43-45]。兰州地区南山剖面约7.2 Ma 风成含量增加,6.5 Ma 风成含量进一步增加^[46]。临夏盆地湖相地层中6.78 Ma 左右碳酸盐和氯离子含量的突变表明气候快速变干^[47]。Sun *et al.*^[48]用高分辨率古地磁定年结合古生物地层法将塔克拉玛干沙漠腹地出现的风沙环境时代下延至7 Ma,并指出7 Ma 前沙漠的形成可能与全球气候变冷和青藏高原北缘的构造隆升导致的雨影效应有关。塔里木盆地在7.1~6.6 Ma 沉积速率明显增加^[49]。Sun *et al.*^[50]塔里木盆地北缘库车前陆盆地研究发现,在7.0~5.3 Ma 出现了一次干旱化事件,与地中海盐度危机有关。7 Ma 左右全球海洋海平面温度降低被论证为大气 CO_2 含量降低,被认为是7 Ma 之后亚洲气候变干^[51-52]。从端元3可以看出(图5),粒度在8.0~6.0 Ma 波动较大。

5.2~4.3 Ma(图5)端元1 粒度含量呈突然减小趋势,端元2 粒度呈缓慢增加趋势,中值粒径也变化明显呈增大趋势,粗粒组分(20 μm)含量自5.2 Ma 呈阶梯式增大,指示了阿尔金地区晚新生代以来的干旱环境持续发展,中值粒径的增大,指示着近地面风力持续增强。4.8 Ma 沉积速率突然增大,指示了5.2 Ma 以来阿尔金地区的干旱环境。5.0 Ma 左右塔里木盆地出现了一次干旱化加剧事件^[50,53-54]。约4.5 Ma 塔克拉玛干沙漠沙层再次扩大,经历4.5 Ma 等多次间歇性扩张,最终形成现今格局^[5,55],阿尔金新近纪晚期红黏土就是在这种背景下堆积形成的。

3.6~2.8 Ma(图5)端元1 细粒组分(5.2 μm)含量整体上呈减小趋势波动较大,端元2 粗粒(20 μm)含量波动较大呈缓慢增加趋势,中值粒径也呈逐渐增加趋势,粗粒百分含量增加指示了干旱化显著,同时,风成粒径的增大指示了近地表风动力显著增强。3.6~2.8 Ma 阿尔金红黏土的沉积速率持续增加,也可能指示了风尘沉积区的干旱化程度加强。3.6~2.6 Ma 海陆风尘通量同步增大指示亚洲内陆粉尘源区干燥度显著加剧^[56]。

4.3 内陆干旱化可能的机制

在全球变冷变干的背景之下,中中新世以来,青藏高原的隆升在亚洲内陆包括阿尔金、塔里木在内的气候环境演化中扮演重要角色,高原的隆升与东亚季风和西风环流有着密切关系(图6),根据上述对阿尔金彩虹沟组红黏土的粒度组成特征,结合前人对其研究的进展表明阿尔金地区13~2.6 Ma 气候演化经历了四个阶段演化气候变化波动较大,内陆干旱化发生时间可能为11 Ma 左右。有证据表明,副特提斯海在晚始新世已经退出了亚洲大陆^[57-58],已经超出此研究时段。新生代全球气候经历了一个MMCO,之后又经历了MMCT^[59],这次变化在磁化率中表现最为明显,气候从暖湿向冷干转变。全球气候转冷减少了水汽循环、增大了海陆面积比并使内陆冷干急流增强^[60],从背景尺度推动内陆干旱化的形成与发展。10.8~10.2 Ma 端元2(粗粒组分)、中值粒径、磁化率以及沉积物的颜色由深到浅中间还夹钙质结核,表明阿尔金地区的这种干旱化趋势与全球降温事件相对应。8.0~6.0 Ma、5.2~4.3 Ma、3.6~2.8 Ma 端元2(粗粒组分)、中值粒径、沉积物的颜色变化频繁表明在这三个时段内陆干旱化都显著增强与此时全球氧同位素含量持续上升,尤其是北极冰盖的形成与扩展^[61]相互吻合。因此,可推断控制阿尔金地区的干

旱化的主导因素为全球变冷。另外,诸多地质记录与气候模型显示青藏高原的阶段性隆升阻碍了水汽向亚洲内陆输送和致使了西风带发生明显的季节性变化及全球冰量的显著增加^[62-66]。因此,13~2.6 Ma 阿尔金地区干旱化进程起主导因素的是全球变冷,青藏高原的阶段性隆升起着推动作用。

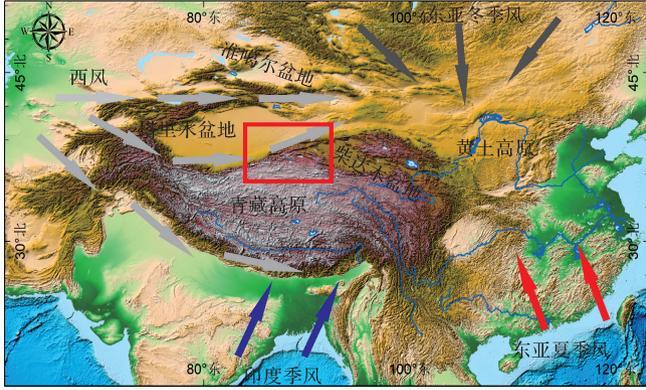


图6 东亚季风与西风环流风场分布图

Fig.6 East Asian monsoon and Westerly map

5 结论

(1) 阿尔金彩虹沟红黏土粒度呈多组分叠加分布,与黄土高原黄土相似呈双峰分布,整个剖面以黏土、极细粉砂、中粉砂和粉砂为主,砂粒的含量较少。通过对彩虹沟剖面粒度数据进行拟合分离得出3个端元分别代表3种风动力方式,分别为高空西风、低空西风和尘暴事件中风动力近源的变化强度反映混合沉积。

(2) 端元1代表高空西风控制下远源背景下做悬移运动粉尘,端元1的峰值主要集中在1~10 μm ,其主峰的众数粒径为5 μm ;端元2的峰值集中在10~100 μm ,其主峰的众数粒径为20 μm ,也有少量较细的黏土存在0.85 μm ,代表低空西风所搬运的短距离做跃移的粉尘物质;端元3其主峰的众数粒径为57 μm ,次主峰众数粒径为2.5 μm ,代表了尘暴事件中风动力近源的变化强度,反映了混合沉积特点。10.8~10.2 Ma 粗颗粒含量增加以近距离低空搬运为主;8.0~6.0 Ma 粉尘来源依旧为近距离粉尘为主,但高空西风贡献相对增强,搬运的动力方式尘暴和非尘暴的共同作用。5.2~4.3 Ma 和3.6~2.8 Ma 粉尘来源依旧为近距离低空搬运为主。

(3) 阿尔金地区新近纪红黏土的3个粒度端元含量变化较大,通过对比同剖面的其他指标及邻区乃至全球气候变化事件发现,13~2.6 Ma 的干旱化过程

是全球变化和青藏高原隆升共同作用。亚洲内陆干旱化的主控因素为全球变冷,青藏高原的阶段性隆升起着推动作用。

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Grain Size Characteristics and Paleoclimate Records of the Neogene Red Clay in Altun, Western China

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Abstract: The Loess Plateau with eolian accumulation is the most widespread and most continuous area in western China. Based on the loess-paleosol sequence and research of the underlying red clay, a series of advances have been made in determining the inland aridity, the evolution of the paleo-monsoon, and its constraints on the uplift of the plateau. The eolian deposits found in the western part of China also provide indispensable data for inland aridity research. Based on previous field investigations, this paper takes the Neogene red clay in the Altun Mountain area on the northeastern margin of Qinghai-Tibet Plateau as the research focus, and based on the magnetic stratigraphy, substitution indices of paleoclimatology, such as magnetic susceptibility, particle size, etc, are used to reconstruct the palaeoclimate evolution process of the Altun area and explore its indicative significance for the aridity of the Asian interior. In this paper, grain size analysis is carried out on the basis of the existing magnetic stratigraphic constraints and the paleo-climatic environment information for the inversion of the Altun Neogene red clay records. The sediment grain size End Member Model (EMM) was decomposed. It can be divided into three End Members; EM1 (mode particle size 5.2 μm) has a concentration size distribution in 2-6 μm , grain size distribution in the westerlies of the North Pacific Ocean, and grain size distribution of Chinese loess. EM2 (Mode Size 20 μm) shows a negative skewed asymmetric distribution, and the Mode Size is between 32-16 μm . It is the dust material, which is moved by the low-level westerly over short distances. The distribution of EM3 is a double main peak, and the particle sizes are 57 μm and 2.5 μm , representing the intensity of near-source variation of wind-stroke dynamics during the duststorm event reflecting the mixed depositional characteristics. During 10.8-10.3 Ma, 8-6 Ma, 5.2-4.3 Ma, and 3.6-2.8 Ma, the particle content of End-Member 1 gradually decreased while the granularity percent content of End-Member 2 shows a gradually increasing trend and medium particle size. The Altun red clay records show that the intensity of the inland drought has gone through four stages: 10.8-10.3 Ma, 8-6 Ma, 5.2-4.3 Ma, and 3.6-2.8 Ma. Combined with previous studies of other geological records for the profile and related geological records of the adjacent areas, the onset time of inland drought may be 11 Ma. The westerly wind is dominant in this area, global cooling is the leading factor of the intensification of inland drought, and the stage uplift of the Tibe-Plateau is promoted.

Key words: Altun; red clay; grain size; Neogene; End Member Model; westerly