西昆仑及邻区新生代差异隆升的热年代学证据

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摘要: 通过总结和分析有关热年代学的资料, 认为西昆仑及邻区的隆升存在明显的时空差异性. 第一, 隆升历史表现出明显的阶段性: 晚渐新世到早中新世(25～16 Ma)的部分隆升阶段、中新世中后期的快速隆升阶段(14～8 Ma)和晚中新世以来的整体强烈隆升阶段(6 Ma 以来). 第二, 隆升在空间上显示出明显的差异性: 塔什库尔干—公格尔山地区的隆升主要集中在 9 Ma 以来, 红其拉甫—库地地区的隆升主要集中在 25～16 Ma, 康西瓦—普鲁地区的隆升则主要在 9 Ma 以来(集中在 9～2 Ma)和 25～12 Ma. 东西方向上表现为东西两端靠近构造结(喜玛拉雅西构造结和西昆仑—阿尔金构造结合部位)的地方较新(主要在 9 Ma 以来), 中间较老(主要在 9 Ma 以前); 南北方向上, 西昆北地体在 20 Ma 左右发生快速隆升, 西昆南地体在 9～5 Ma 发生快速隆升, 而甜水海地体在 5～2 Ma 发生快速隆升, 由北向南总体上呈现出由老到新的空间差异性.

关键词: 西昆仑; 新生代; 磷灰石; 热年代学; 差异隆升; 青藏高原.
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Thermochronological Evidence of the Cenozoic Differential Uplift Processes of the West Kunlun and Its Adjacent Area

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Abstract: Thermochronological data suggests that spatial-temporal differences of uplift obviously exist in West Kunlun and its adjacent area. Firstly, the uplift history falls into three distinct stages: The partial uplift stage from Late Oligocene to Early Miocene (25—16 Ma), the rapid uplift stage during Middle Miocene (14—8 Ma) and the holistic and strong uplift stage since Late Miocene (after 6 Ma). Secondly, the uplift of the study area shows obvious spatial differences. The uplift of Kongur-Tash Gurgan area mainly occurred after 9 Ma; the uplift of Hongqilapu-Kuda area mainly occurred during 25—16 Ma, and the uplift of Kangxiwar-Pulu area mainly occurred after 9 Ma (especially 9—2 Ma) and during 25—12 Ma. In the east/west direction, the uplift is earlier near the syntaxises (western Himalayan Syntaxis and West Kunlun-Altyn Syntaxis) than that in the middle area. Near the syntaxises the uplift mainly occurred after 9 Ma and yet in the middle area mainly before 9 Ma. In the south/north direction, the rapid uplift of northern West Kunlun terrane roughly occurred at 20 Ma; the rapid uplift of southern West Kunlun terrane mainly occurred during 9—5 Ma; the rapid uplift of Tianshuihai terrane mainly occurred during 5—2 Ma. The rapid uplift of southern West Kunlun and its adjacent area is later than that in the north, and it varies from old to new.

Key words: West Kunlun; Cenozoic; apatite; thermochronology; differential uplift; Qinghai-Tibet plateau.

西昆仑及邻区是青藏高原晚新生代强烈变形的地区之一, 其新生代的构造演化涉及青藏高原形成、扩展机制和环境效应等重大问题. 因此, 一直以来都是国际地质学界研究的热点地区. 近几十年来,

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国内外许多学者通过热年代学方法(裂变径迹和 $^{40}Ar/^{39}Ar$ 测年)对西昆仑及邻区的冷却剥露过程进行了定量研究(Arnaud, 1992; Arnaud *et al*., 1993; 王军, 1998; 王军等, 1999; Cowgill, 2001; 王彦斌等, 2001; 万景林和王二七, 2002; 王永等, 2002; Wang *et al*., 2003; Robinson *et al*., 2004, 2007; 黎敦朋等, 2007), 不同的学者通过对研究区不同部位的研究来探讨整个西昆仑及邻区乃至整个青藏高原的冷却剥露历史, 缺乏从研究区整体的时空差异性角度来系统全面地分析和限定其冷却剥露历史. 本文广泛收集了前人报道过的热年代学年龄, 结合项目在柯克亚地区所做的碎屑锆石裂变径迹年龄, 通过系统分析和对比来探讨研究区新生代以来的冷却剥露过程及其驱动机制, 并进一步探讨青藏高原的隆升过程.

1 地质背景

研究区涉及西昆仑山、喀喇昆仑山北坡和帕米尔东部地区, 位于青藏高原的西北缘, 塔里木盆地西南缘, 南接藏北地块, 东端以阿尔金断裂带与东昆仑分开, 西端延伸至境外. 由北向南发育一系列大型断裂带, 依次为铁克里克断裂(TKF)、主帕米尔逆冲断层(MPT)、库地断裂(KDF)、盖孜西－库地南断裂(GKF)、康西瓦断裂(KXF)、阿尔金断裂(ATF)和喀喇昆仑断裂(KKF), 这些断裂把研究区自北向南分为西昆北地体、西昆南地体和甜水海地体3个部分(图1)(潘裕生, 1990; 丁道桂等, 1996; 潘桂棠等, 2004; Wang, 2004; 刘训等, 2006). 西昆北地体主体主要由前震旦系深变质岩构成, 上部发育晚石炭世－早二叠世沉积盖层, 南部出露大面积的花岗岩

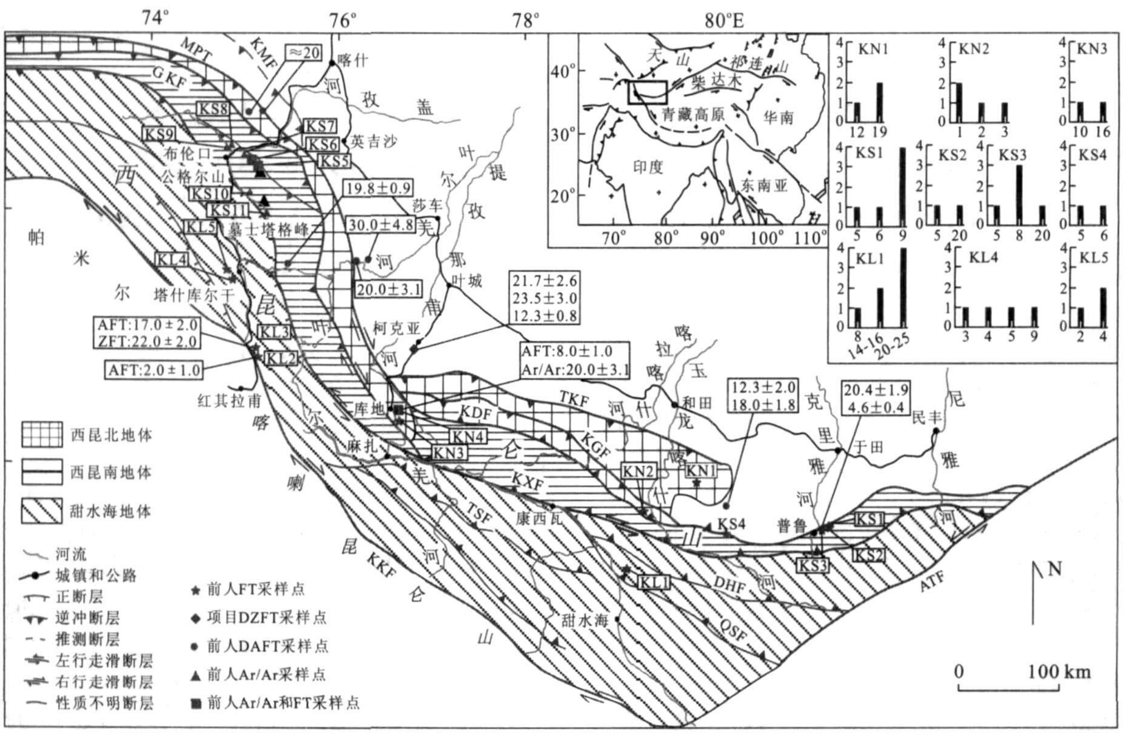

图1 西昆仑及邻区构造简图及热年代学样品位置和年龄分布

Fig. 1 Simplified structural map of West Kunlun and adjacent area, locations of the thermochronological samples and distribution of the thermochronological ages

KN、KS、KL分表表示西昆北地体、西昆南地体和甜水海地体的样品分布频数图, 频数图的横坐标单位均为Ma, 纵坐标单位均为个; 矩形方框内的年龄单位为Ma. AFT(apatite fission track)表示磷灰石裂变径迹; ZFT(zircon fission track)表示锆石裂变径迹; DAFT(detrital apatite fission track)表示碎屑磷灰石裂变径迹; DAFT(detrital zircon fission track)表示碎屑锆石裂变径迹; 碎屑磷灰石和锆石的裂变径迹年龄取最年轻组分的峰值年龄, 单位为Ma; Ar/Ar表示 $^{40}Ar/^{39}Ar$ 测年. TKF. 铁克里克断裂; MPT. 主帕米尔逆冲断层; GKF. 盖孜西－库地南断裂; KMF. 库姆塔格断裂; KGF. 柯岗断裂; KXF. 康西瓦断裂; DHF. 大红柳滩断裂; QSF. 泉水沟断裂; TSF. 甜水海断裂; ATF. 阿尔金断裂; KKF. 喀喇昆仑断裂. 热年代学数据来自Arnaud(1992)、Arnaud *et al*.(1993)、王军等(1999)、Cowgill(2001)、王彦斌等(2001)、万景林和王二七(2002)、王永等(2002)、Wang *et al*.(2003)、Robinson *et al*.(2004, 2007)、黎敦朋等(2007). 该图据潘裕生(1990)、新疆维吾尔自治区地质矿产局(1993)、Arnaud *et al*.(1993)、丁道桂等(1996)、Sobel(1999)、潘桂棠等(2004)、Wang(2004)、王国灿等(2005)、刘训等(2006)、崔军文等(2006)、Valli *et al*.(2007)修改

侵入体(刘训等, 2006), 南界出露奥依塔格—库地蛇绿岩带(潘裕生, 1994; 邓万明, 1995; 丁道桂等, 1996; Yang *et al*., 1996; 杨树锋等, 1999); 西昆南地体主体由变质的前古生界岩层和大面积的花岗侵入岩体所组成(汪玉珍和方锡廉, 1987; 潘裕生, 1990; 刘训等, 2006); 甜水海地体基底主要由古元古界和长城系中深变质杂岩组成, 上覆早奥陶世、志留纪、二叠纪、三叠纪、中侏罗世和晚白垩世的沉积盖层, 中—酸性岩浆侵入活动比较强烈(丁道桂等, 1996; 刘训等, 2006).

2　研究区隆升历史的阶段性划分

综合前人在研究区所报道过的 180 多个热年代学年龄(其中$^{40}Ar/^{39}Ar$年龄 61 个, 锆石裂变径迹 2 个, 其余均为磷灰石裂变径迹年龄), 结合柯克亚地区所做的碎屑锆石裂变径迹年龄, 系统全面地探讨了西昆仑及邻区的隆升过程. 分析结果显示, 西昆仑及邻区在新生代的隆升剥露主要发生在晚渐新世以来, 呈现出 3 个明显的隆升剥露阶段: 25 ~ 16 Ma、14 ~ 8 Ma 和 6 Ma 以来(图 2).

2.1　晚渐新世到早中新世的隆升阶段(**25 ~ 16 Ma**)

研究区在 25 ~ 16 Ma 的热年代学年龄主要分布在西昆仑山前和塔里木盆地边缘(图 1). 25 Ma 左右, 西昆仑开始南北向缩短(Coutand *et al*., 2002), 西昆仑山前由海相环境变为陆相环境(Jin *et al*., 2003; 王永等, 2006); 24.8 ~ 7.9 Ma, 甜水海地体去顶 3 000 m(黎敦朋等, 2007). Wang *et al*. (2003)通过对西昆仑普鲁地区裂变径迹的研究表明青藏高原西北缘的快速冷却事件开始于 20 ~ 18 Ma. Cowgill(2001)在西昆仑山前新生代逆冲地

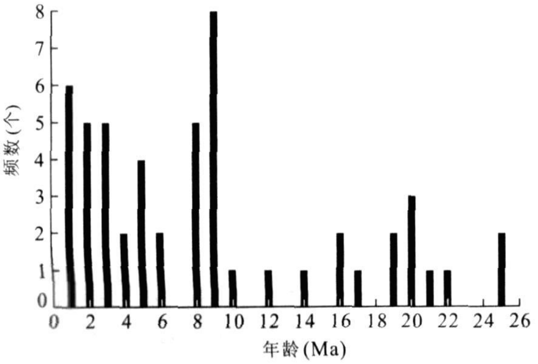

图 2　西昆仑及邻区磷灰石裂变径迹年龄直方图

Fig. 2　The histogram of apatite fission track ages in the West Kunlun and adjacent area

层下盘片麻岩中获得 13.7 ~ 22.1 Ma 的磷灰石裂变径迹年龄. 20 Ma 左右, 主帕米尔逆冲断裂带(MPT)和奥姆塔格断裂带(KMT)开始活动, 西昆仑地区地壳增厚, 西昆仑山前地带发生隆升剥蚀(Arnaud, 1992; Sobel and Trevor, 1997); 25 ~ 20 Ma, 青藏高原北部山脉发生快速剥露事件(Sobel and Trevor, 1997); 20 ~ 18 Ma, 布伦口地区发生岩浆活动(Arnaud, 1992); 25 ~ 23 Ma 以前, 喀喇昆仑断裂形成, 青藏高原西部发生大规模右旋走滑(Lacassin *et al*., 2004; 李海兵等, 2006); 25 ~ 17 Ma, 高原面隆升达到 2 000 m 左右, 亚洲季风替代先前的行星风系(施雅风等, 1998, 1999); 22 Ma, 亚洲内陆开始干旱化(Guo *et al*., 2002). 上述事件的发生时间和研究区的热年代学记录的隆升剥露时期具有很好的一致性. 该阶段为西昆仑的部分隆升阶段, 可能与南部印度板块向欧亚板块挤压并产生强烈俯冲, 加之北部塔里木块体的阻挡, 岩石圈发生拆沉作用并造成西昆仑南北向缩短有关(Harrison *et al*., 1992, 1998; Yin *et al*., 1994; Chemenda *et al*., 2000; 许志琴等, 2006).

2.2　中新世的隆升阶段(**14 ~ 8 Ma**)

研究区在 14 ~ 8 Ma 的热年代学年龄主要分布在西昆仑西部和东部地区. 14 ~ 8 Ma, 甜水海地体发生去顶作用(黎敦朋等, 2007); 12 ~ 8 Ma, 西昆仑普鲁地区发生快速冷却事件(Wang *et al*., 2003); 9 ~ 8 Ma, 西昆仑北部山前发生抬升作用(万景林和王二七, 2002); 8 ~ 7 Ma, 公格尔山张性断裂带发生东西向延伸并引发垂向剥蚀(Robinson *et al*., 2004, 2007), 导致公格尔山至慕士塔格峰北西向山链的强烈隆升剥露(图 1 中的 KS8、KS9、KS10 和 KS11 为$^{40}Ar/^{39}Ar$样品位置), 该事件也被山前现代河流中的碎屑锆石裂变径迹年龄所记录(另文发表). 王彦斌等(2001)通过对西昆仑山新藏公路沿线出露的花岗岩体的裂变径迹研究认为西昆仑山在中新世发生过一次抬升作用. 10 Ma, 阿尔金山发生快速隆升(Jolivet *et al*., 1999); 中新世到第四纪, 西昆仑山前前陆盆地的沉降中心向北迁移至叶城—喀什一带, 快速的沉降作用堆积了 5 000 ~ 6 000 m 的粗碎屑沉积物(丁道桂和罗月明, 2005); 16 ~ 14 Ma, 阿尔金断裂的左行走滑加强(Wang, 1997; Yue and Liou, 1999); 17 ~ 11 Ma, 喀喇昆仑断裂发生转换和逆冲作用(Matte *et al*., 1996; Murphy *et al*., 2000), 12 Ma 左右发生活动, 噶尔盆地形成, 阿依拉日居山快速隆升(李海兵等, 2006); 8 Ma, 阿尔

金断裂发生快速左行走滑(陈正乐等, 2002).10~8 Ma, 东亚季风形成, 亚洲内部干旱化加剧(Harrison *et al*., 1992; Molnar *et al*., 1993; An *et al*., 2001); 8 Ma, 印度洋季风的加强(Jay *et al*., 1989; Molnar *et al*., 1993), 阿拉伯海上涌流出现(Kroon *et al*., 1991); 7 Ma, 塔克拉玛干大沙漠形成(Sun *et al*., 2009).上述事件的发生时间和研究区热年代学记录的冷却剥露时期具有明显的一致性, 表明西昆仑及邻区乃至高原西北缘经历快速隆升剥露, 并很可能对青藏高原内部及周缘的气候产生重大影响.该阶段, 印度板块向欧亚大陆持续挤压, 由于塔里木板块的水平阻挡作用, 青藏高原岩石圈上地幔发生"对流剥离"(陈正乐等, 2006), 加速了研究区的隆升剥露.

2.3 晚中新世以来的隆升阶段(6 Ma 以来)

6 Ma 以来的热年代学年龄在研究区广泛分布.5~4.8 Ma, 青藏高原西北缘的普鲁地区发生过一次快速冷却事件(Wang *et al*., 2003); 5 Ma 左右, 西昆仑山前磨拉石发育, 西昆仑山开始快速隆升(Zheng *et al*., 2000; 万景林和王二七, 2002; 王永等, 2006); 5 Ma 以来, 塔什库尔干地区发生脉动式隆升, 5~2 Ma 隆升速率约为 0.1 mm/a; 2 Ma 以来, 隆升速率增至2 mm/a(王军, 1998); 5 Ma 以来, 公格尔山发生冷却事件, 2 Ma 时发生突变, 平均冷却速率从 20 ℃/Ma 变为 150 ℃/Ma (Arnaud *et al*., 1993).2.9~0.9 Ma, 西昆仑南部发生快速隆升(黎敦朋等, 2007); 晚上新世—早更新世以来, 西昆仑山的最低隆升速率为 0.21~0.25 mm/a.100 ka 以来的隆升速率为 1.5 mm/a (潘家伟等, 2007); 2~1.5 Ma, 喀喇昆仑断裂带的最北段发生正断作用, 导致正断层东北侧前新生代地质体快速抬升, 速率为 1~4 mm/a(Brunel *et al*., 1994); 康西瓦断裂全新世以来的滑移速率约为16.1 mm/a(李海兵等, 2008).1.2 Ma 左右, 西昆仑及邻区河流开始下切形成阶地, 第四纪中晚期以来西昆仑地区构造抬升幅度与频率加快(王永等, 2006).陈杰等(2001)通过塔里木西南缘普遍发育的西域砾岩的研究认为西域砾岩具有穿时性, 开始沉积于 4.6~3.5 Ma.郑洪波等(2002, 2003)和刘训等(2002)通过塔里木南缘叶城剖面古地磁测试并结合砂岩和砾石组分的分析认为青藏高原北缘山系在 4.6 Ma 时开始隆升, 在 3.5 Ma 加速隆升, 在2.4 Ma以前发生大规模隆升.张克信等(2007)根据整个青藏高原盆地古近纪—新近纪沉积盆地的演化认为中—上新世西昆仑经历大幅度隆升.1.6~1.0 Ma, 西昆仑山发生火山作用, 形成大范围的火山沉积(Liu and Maimaiti, 1989); 5.3 Ma 左右, 塔克拉玛干沙漠干旱化加剧(Sun and Liu, 2006; Sun *et al*., 2008); 3.6~2.6 Ma, 东亚季风加强, 输入到北太平洋的风成物质增加(Rea *et al*., 1998; An *et al*., 2001).上述事件的发生时间和研究区热年代学记录的隆升剥露时期也具有较好的匹配性, 该阶段为西昆仑及邻区的整体强烈隆升期, 进一步对青藏高原的气候产生重大影响.

综上所述, 研究区的隆升历史表现出明显的阶段性, 可以划分为晚渐新世到早中新世(25~16 Ma)的部分隆升阶段、中新世中后期的快速隆升阶段(14~8 Ma)和晚中新世以来的整体强烈隆升阶段(6 Ma 以来).

3 研究区隆升的空间差异性

通过系统对比西昆仑及邻区的热年代学年龄, 揭示了研究区的隆升剥露无论是在东西方向上, 还是在南北方向上均具有明显的差异性(图 3).

3.1 东西方向上的差异隆升

研究区从西昆仑与阿尔金结合部位的普鲁地区到靠近喜马拉雅构造结的布伦口地区的热年代学年龄表现出明显的差异性.塔什库尔干—公格尔山地区的隆升主要集中在 9 Ma 以来(图 3a), 现代河流碎屑锆石裂变径迹也有很好的记录(另文发表), 该地区靠近喜马拉雅构造结, 其年轻的剥露除了与青藏高原的均衡调整引起的快速隆升有关外(李吉均和方小敏, 1998; Zheng *et al*., 2000), 还很可能与气候有关(Rea *et al*., 1998; An *et al*., 2001).红其拉甫—库地地区的隆升主要集中在 25~16 Ma(图 3b), 该地区的隆升在一定程度上受到印度板块向欧亚板块的强烈俯冲影响(Harrison *et al*., 1992; 高锐等, 2001; 崔军文等, 2006).康西瓦—普鲁地区的隆升主要在9 Ma以来(集中在 9~2 Ma)和 25~12 Ma(图 3c), 该地区处于西昆仑与阿尔金的结合部位, 是青藏高原北缘隆升最强烈的地区之一(黎敦朋等, 2007), 阿尔金断裂和康西瓦断裂是该结合部位最重要的两条大型断裂带.阿尔金断裂自渐新世以来发生过多期活动(陈正乐等, 2002; 崔军文等, 2002; 李海兵等, 2006), 这些活动对阿尔金山的隆升剥露起到了巨大作用(陈正乐等, 2006; 袁四化等,

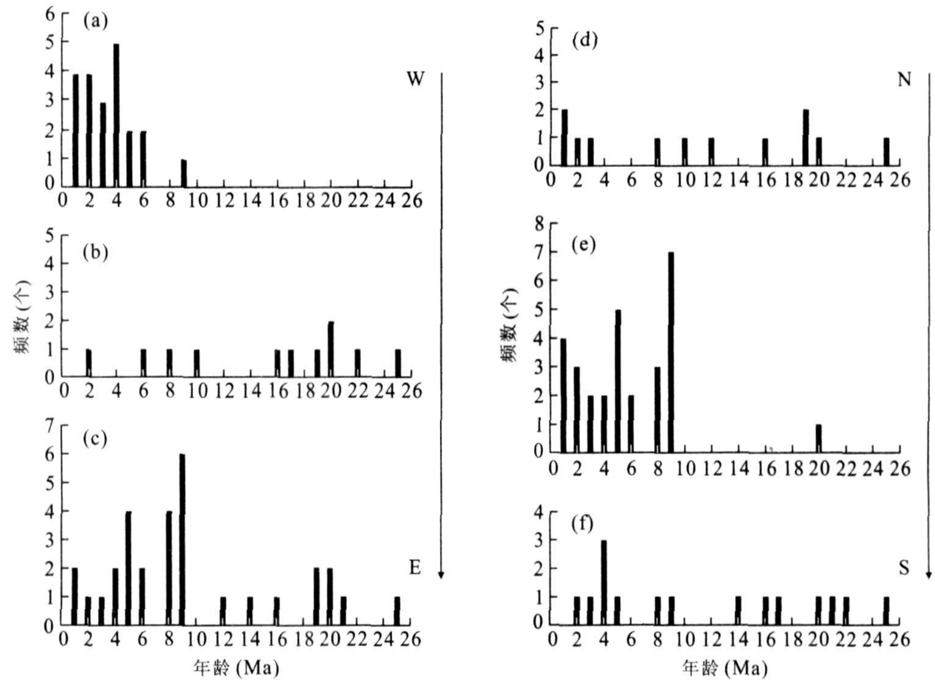

图 3 西昆仑及邻区热年代年龄空间差异性直方图

Fig. 3 Histogram of the spatial difference of thermochronological ages in the West Kunlun and adjacent area

东西方向: a. 公格尔山一塔什库尔干; b. 红其拉甫一库地; c. 康西瓦一普鲁; 南北方向: d. 西昆北地体; e. 西昆南地体; f. 甜水海地体

2006 ;刘永江等, 2007). 康西瓦断裂在喜马拉雅运动早期发生 SE—NW 向挤压, 在喜马拉雅运动晚期发生伸展与快速隆升作用(刘强等, 2003), 晚第四纪以来又发生强烈活动(Peltzer *et al.*, 1989; 付碧宏等, 2006; Zhang *et al.*, 2007; 李海兵等, 2008). 从阿尔金断裂和康西瓦断裂的活动时间与该地区隆升剥露时期的匹配关系可以推断, 这两条断裂带的活动性对区域性隆升剥露起到了较强的推动作用(杨万志等, 2005; 李海兵等, 2006). 因此, 西昆仑及邻区的隆升剥露表现为东西两端靠近构造结的区域较新(主要在 9 Ma 以来)和中间区域较老(主要在 9 Ma 以前)的空间差异性.

3.2 南北方向上的差异隆升

研究区的热年代学年龄在西昆北地体、西昆南地体和甜水海地体之间也表现出较明显的差异性. 西昆北地体的隆升在 8 Ma 以前, 主要集中在 20 Ma 左右(图 3d), 另外, 西昆北地体及盆地周缘的碎屑磷灰石和锆石裂变径迹年龄大部分也呈现出 20 Ma 左右的最年轻峰值年龄(Sobel and Trevor, 1997). 结合沉积(Jin *et al.*, 2003; 王永等, 2006)和气候(施雅风等, 1998, 1999; Guo *et al.*, 2002)证据, 西昆北地体在 20 Ma 左右存在快速隆升事件. 西昆南地体隆升主要在 9 Ma 以来, 9~5 Ma 形成明显峰值(图 3e), 由于西昆南地体的热年代学年龄主要分布在康西瓦一普鲁和塔什库尔干一公格尔山两个构造结合部位, 9 ~5 Ma, 西昆南受大型断裂带活动的影响而快速隆升剥露(刘强等, 2003, 杨万志等, 2005; 李海兵等, 2006). 甜水海地体的热年代学年龄主要集中在 9 ~ 2 Ma, 特别是 5 ~ 2 Ma 形成较明显峰值(图 3f). 王军(1998)对塔什库尔干地区的磷灰石裂变径迹研究表明: 5 Ma 以来, 甜水海地体西部发生脉动式隆升, 5 ~2 Ma 隆升速率约为0. 1 mm/a增至 2 Ma 以来的 2 mm/a, 因此, 甜水海地体在 5 ~ 2 Ma 存在快速隆升事件. 综上所述, 西昆北地体在 20 Ma 左右发生快速隆升事件, 西昆南地体在 9 ~ 5 Ma 快速隆升, 而甜水海地体在 5 ~ 2 Ma 快速隆升. 因此, 西昆仑及其邻近地区发生快速隆升的时间由北向南总体上呈现出由老到新的空间差异性.

4 西昆仑及邻区以及高原的隆升机制

50 Ma 左右, 印度与欧亚大陆的新生代碰撞及其后持续的汇聚作用形成当今世界上最雄伟的青藏高原(Besse *et al.*, 1984; Patriat and Achache, 1984; Rowley, 1996). 高原的形成以及横向和垂向上的生长影响了区域和全球气候的变化趋势(Rud-

diman *et al*., 1989; Kutzbach *et al*., 1993; Liu and Yin, 2002), 同时还影响流域模式及盆地和海洋中沉积物的堆积(李吉均和方小敏, 1998; Rea *et al*., 1998; Zheng *et al*., 2000; Clark *et al*., 2004). 作为对青藏高原新生代构造过程反应十分敏感的西昆仑及邻区在新生代呈现出3个快速的隆升剥露时期: 25~16 Ma、14~8 Ma和6 Ma以来. 这3个快速隆升阶段在青藏高原也具有一定的普遍性(钟大赉和丁林, 1996; 李吉均和方小敏, 1998; 安芷生等, 2006).

25~16 Ma, 印度板块在向欧亚大陆持续俯冲挤压, 加之塔里木板块的水平阻挡作用(Xiao *et al*., 2001), 岩石圈发生拆沉作用(Harrison *et al*., 1992; Yin *et al*., 1994; Harrison *et al*., 1998; Chemenda *et al*., 2000; 崔军文等, 2006; 许志琴等, 2006), 使得整个高原向东、向北和向上生长, 并伴随着强烈的岩浆侵入、火山喷溢作用(Arnaud, 1992; Turner *et al*., 1993; Harrison *et al*., 1998; Ding *et al*., 2003)以及大型断裂带的活动(钟大赉等, 1989; Tapponnier *et al*., 1990; Hodges *et al*., 1992; Hendrix *et al*., 1994; Yin *et al*., 1994; Sobel and Trevor, 1997; 李海兵等, 2006). 此时, 西昆仑及邻区经历了新生代的部分隆升阶段(Arnaud, 1992; Sobel and Trevor, 1997; Cowgill, 2001; Wang *et al*., 2003; 黎敦朋等, 2007), 并且地处中亚腹地的天山山脉也开始了其新生代的隆升剥露(Hendrix *et al*., 1992).

14~8 Ma, 随着印度板块向欧亚大陆进一步持续挤压和塔里木板块的水平阻挡作用, 青藏高原岩石圈上地幔发生"对流剥离"(Harrison *et al*., 1992; Molnar *et al*., 1993), 青藏高原向北部及东部的范围明显扩大(Turner *et al*., 1993; Meyer *et al*., 1998; Tapponnier *et al*., 2001; Wang *et al*., 2003; 张培震, 2006), 西昆仑及邻区乃至整个高原的北缘山脉出现快速的隆升剥露(Jolivet *et al*., 1999; 万景林和王二七, 2002; Wang *et al*., 2003; Robinson *et al*., 2004), 并对亚洲的气候产生了巨大影响(Jay *et al*., 1989; Harrison *et al*., 1992; Molnar *et al*., 1993; An *et al*., 2001).

6 Ma以来, 青藏高原的均衡调整(李吉均和方小敏, 1998; 王国灿等, 2005)和气候(Zhang *et al*., 2001)共同引发了西昆仑及邻区和整个高原的快速隆升, 导致了高原周边一系列盆地内沉积速率的加快和磨拉石建造的发育(李吉均和方小敏, 1998; Zheng *et al*., 2000; 陈杰等, 2001; 万景林和王二七, 2002; 王永等, 2006). 李吉均和方小敏(1998)以及李吉均(1999)认为3.6~1.7 Ma青藏高原北缘山脉普遍发生隆升作用, 开始奠定青藏高原周边和中国西部的主要山川地貌、河流水系以及气候格局(Rea *et al*., 1998; An *et al*., 2001; Sun and Liu, 2006; 王永等, 2006; Sun *et al*., 2008, 2009); 2.6 Ma以来, 高原则表现为多次脉动式隆升(安芷生等, 2006).

5 结论

(1)西昆仑及邻区的隆升历史表现出明显的阶段性: 晚渐新世到早中新世(25~16 Ma)的部分隆升阶段、中新世中后期的快速隆升阶段(14~8 Ma)、晚中新世以来的整体强烈隆升阶段(6 Ma以来). 25~16 Ma的隆升可能与印度板块向欧亚大陆持续俯冲挤压、塔里木板块的水平阻挡作用及岩石圈发生拆沉造成的西昆仑南北向缩短有关; 16~8 Ma的隆升可能与印度板块和欧亚板块的进一步持续挤压和塔里木板块的水平阻挡作用, 青藏高原岩石圈上地幔"对流剥离"作用有关; 6 Ma以来的隆升则很可能是构造和气候共同作用的结果.

(2)西昆仑及邻区的隆升表现出明显的空间差异性. 塔什库尔干—公格尔山地区的隆升则主要集中在9 Ma以来, 红其拉甫—库地地区的隆升主要集中在25~16 Ma, 康西瓦—普鲁地区的隆升主要在9 Ma以来(集中在9~2 Ma)和25~12 Ma. 东西方向上表现为东西两端靠近构造结(喜玛拉雅西构造结和西昆仑—阿尔金构造结合部)的地方较新(主要集中在9 Ma以来), 中间较老(主要在9 Ma以前); 南北方向上, 西昆北地体在20 Ma左右发生快速隆升事件, 西昆南地体在9~5 Ma快速隆升, 而甜水海地体在5~2 Ma快速隆升, 西昆仑发生快速隆升的时间由北向南总体上呈现出由老到新的空间差异性.

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