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新近纪早期青藏高原北部构造隆升研究进展

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摘　要

新生代以来，随着印度板块与欧亚大陆发生碰撞，引起了亚洲大陆古生代和中生代的古老构造带的再次活化。青藏高原北缘的基岩和沉积盆地内的碎屑沉积物详细地记录了不同时期的构造隆升情况。本文利用盆山耦合的思想，通过对青藏高原北缘的低温热年代学、沉积学的研究结果汇总，结合区域内盆地沉降、大型走滑和逆冲断裂的活动时间，发现青藏高原北缘在早－中中新世经历了快速的隆升过程。在高原西北缘主要通过陆内地壳缩短、塔吉克－塔里木盆地基底向南深俯冲、主帕米尔－喀什叶城转换体系－喀喇昆仑断裂的活动来吸收和调节地形变形；在东北端，主要依靠阿尔金走滑断裂的迁移发生的侧向移动，所引起的陆内俯冲作用、地壳缩短过程来实现。青藏高原北部的地质框架在新近纪早期开始初步建立。

关键词

新近纪，青藏高原北缘，构造隆升

A Review of the Neogene Tectonic Evolution of the Northern Tibetan Plateau

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Abstract

The Indian plate has collided with the Eurasia since the early Cenozoic, which reactivated the Paleozoic and Mesozoic tectonic belts in the Central Asia. The low-temperature thermochronology and detrital sediments from the bedrocks and sedimentary basins can be used to constrain the uplifting time of mountains at different periods around the northern margin of Tibetan Plateau. In

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this study, based on the conception of basin-range coupling, we have summarized the results of thermochronology and sedimentology, coupled with the active timing of the basin subsidence and large-scale reversed and strike-slip faults to show that the fast tectonic uplift can be found at early-middle Miocene. The deformations had been accommodated by the intro-continental crustal shortening, basin subduction, large-scale thrusting and strike-slip faults movement in the northwest margin of Tibetan Plateau. In contrast, the Altyn Tagh strike-slip fault had migrated northeastwards that actuated the intro-continental subduction and crustal shortening paying the important role to accommodate the tectonic stress in the northeastern part of Tibetan Plateau. The geological framework has been built in the northern edge of Tibetan Plateau at early Neogene.

Keywords

Neogene, Northern Tibetan Plateau, Tectonic Uplift

1. 引言

新生代早期，印度板块与欧亚大陆发生碰撞，同时受到新特提斯洋洋壳的下沉拖拽，印度板块向欧亚大陆俯冲引起了青藏高原的隆升[1] [2]，导致了亚洲大陆古生代和中生代的古老构造带的再次活化[3] [4]。青藏高原北部新生代以来的构造格架何时建立起来，目前还处于争论之中[5] [6] [7] [8]。主要有两种构造演化模型被提出：(1) 青藏高原北缘的隆升与印度板块和欧亚大陆碰撞的时间同步，即发生在新生代早期[6]; (2) 青藏高原自新生代以来经历了由南向北的逐渐隆升过程，高原北部在新生代晚期发生隆升[5]。

由于印度板块和塔里木板块的相向运动，在高原西北边缘，塔里木和塔吉克盆地基底沿西昆仑－帕米尔－兴都库什山脉一线向南发生俯冲，导致西昆仑、帕米尔、兴都库什地块在新生代的快速隆升并遭受强烈的地表剥蚀，这些碎屑沉积物被搬运至塔里木和塔吉克盆地内，详细记录了高原西北部的隆升及后期地层变形的信息[9] [10] [11] (图 1)。同时在高原的东北缘，沿着与阿尔金左行走滑断裂斜交的山脉山前发育了一系列的山间盆地，其中的碎屑沉积物详细记录了有关走滑断裂转换为山体隆升的活动时间信息，直接记录了高原东北缘的隆升情况[12] [13] [14] [15]。因而本文利用盆山耦合的思想，从盆地沉积学、低温热年代学等方面的研究结果入手，对新近纪早期青藏高原北部的构造隆升过程的研究成果进行梳理，从而为进一步厘清高原北部的构造格局的演化提供有借鉴性的结果。

2. 地质背景

2.1. 造山带

西昆仑造山带(长 700 km、宽 200 km)位于青藏高原西北缘，是“特提斯构造域”与“古亚洲构造域”转换的地带，南抵康西瓦谷地，北侧与塔里木盆地相接，东部与阿尔金左行走滑断裂衔接，西侧以喀喇昆仑山右行走滑断裂为界与帕米尔高原相连[16] [17]。西昆仑造山带演化自大尺度的俯冲－增生体系，包含复理石沉积物和花岗岩侵入体，从早古生代到早中生代，由北昆仑、南昆仑和喀喇昆仑三个主要的地块碰撞所形成。

阿尔金山位于塔里木盆地的东南缘(长 600 km、宽 150 km)。阿尔金山南侧被阿尔金左行走滑断裂带所围限，其北侧被北阿尔金左行走滑断裂带所界定。阿尔金山主要包含前寒武的片麻岩和片岩以及古生

代和中生代时期的类花岗岩[18]。塔东南盆地与阿尔金山之间存在薄皮构造，塔里木板块向东南方向俯冲，导致了阿尔金山的隆升[19]。

青藏高原东北端的祁连山脉高度在 5~4 km，宽度上百千米，北西 – 南东向分布，发育在中 – 上地壳，可分为南祁连山、中祁连山和北祁连山，这些山脉自西南向东北平行分布，中间被山间盆地所分隔[20] [21]。

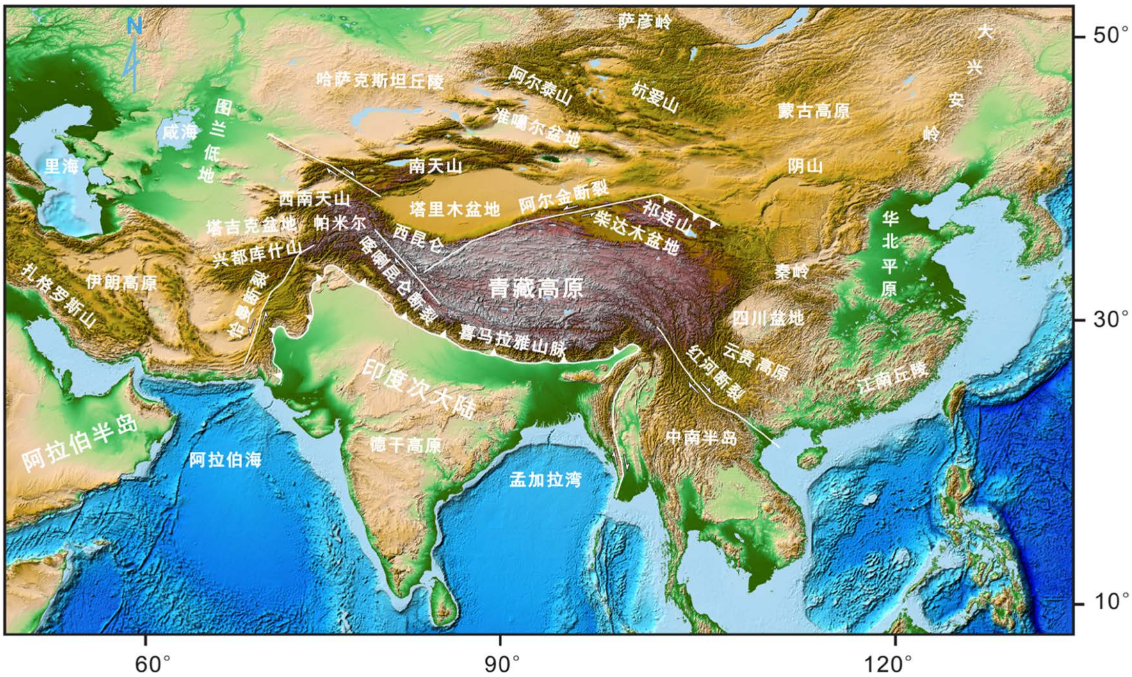

Figure 1. Map of the Tibetan Plateau and surrounding area in Asia
图 1. 青藏高原及周缘主要构造单元位置图

2.2. 沉积盆地

2.2.1. 塔里木盆地

塔里木盆地，位于帕米尔高原和西昆仑山脉的北侧，南天山的东侧，西昆仑和阿尔金山前形成了塔西南和塔东南坳陷，其内沉积了巨厚(超过 10 km)的碎屑沉积层，受到山前逆冲断裂的影响这些地层都不程度出现变形、甚至倒转的现象[22]。

宽波段地震剖面资料解译结果表明，塔里木盆地基底俯冲至西昆仑山脉的岩石圈底部，形成了南倾的俯冲带，深度达到了 300~80 km，地表则形成了向北迁移的逆冲断裂带[22] [23] [24] [25]。新生代晚期出现在西昆仑山脉的高钾岩浆岩代表了这一俯冲过程后期出现的岩浆活动[25]。塔里木盆地基底东南部俯冲至阿尔金山脉之下，形成了倾向南 – 南东的俯冲带，深度达到了 140 km [26]。北向逆冲扩展作用在塔西南和塔东南至~23~20 Ma [27] [28] 和 22~18 Ma [11] [29]以来达到高峰(图 2)。

2.2.2. 塔吉克盆地

塔吉克盆地北面和西面分别被西南天山和吉萨尔山所包围，东面和南面为帕米尔高原和兴都库什山所界定[30]。自印度 – 欧亚大陆新生代发生碰撞以来，在塔吉克盆地主要通过盆地基底的向西挤出、逆时针旋转及山前逆冲褶皱带引起的地壳缩短来吸收[31] [32]。地震剖面解译资料显示，塔吉克盆地的基底向南和南东方向分别向兴都库什山和帕米尔之下俯冲，俯冲深度达到了 250~70 km [30]，在早中新世进入前陆盆地演化阶段[8] [30] (图 2)。

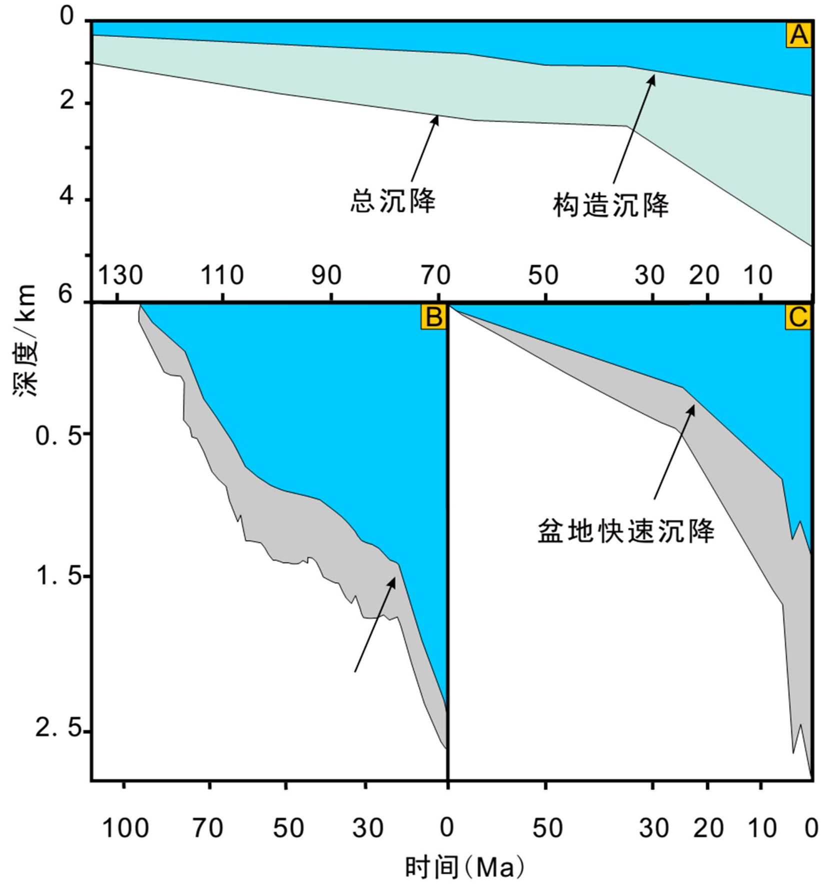

Figure 2. Subsidence analysis for the (A) Southwest Tarim basin [33], (B) Tajik basin [8], and (C) Southeast Tarim basin [34], respectively

图 2. 盆地沉降分析结果示意图：(A) 塔西南盆地[33]；(B) 塔吉克盆地[8]；(C) 塔东南盆地[34]

2.2.3. 柴达木盆地

柴达木盆地具有长方形的外部轮廓，南部接东昆仑山脉，东北缘被党河南山和南祁连山山前逆冲带所围限，西侧被阿尔金山包围[35]。古新世和始新世的河流相沉积厚度达到了 800 m，且主要分布在盆地的西北部和东北缘。渐新世–中新世地层厚~3000 m，主要由湖相和洪积扇相地层组成。从渐新世开始，随着阿尔金左行走滑断裂向北东方向移动，柴达木盆地进入强烈挤压的山间盆地发展阶段，晚渐新世(28~24 Ma)柴达木盆地向南以低角度俯冲至东昆仑山脉之下，深度达到了 150~50 km [36] [37]。随着阿尔金山脉的隆升，在中中新世成为完全封闭的盆地，并在盆地的南部形成了巨厚的沉积中心，并随时间推移向东侧移动[6] [21] [38]。柴达木盆地与塔吉克盆地和塔里木盆地相比而言，前者主要位于青藏高原内部，深受阿尔金走滑断裂的影响。

2.3. 走滑断裂带

喀喇昆仑右行走滑带自青藏高原东南端的冈仁波齐山脉一直延伸到中帕米尔，构成了帕米尔高原东南部的边界[39]。进入到始新世(40 Ma)，喀喇昆仑走滑断裂开始初步活动，并在 25~23 Ma 进入快速走滑阶段，形成了 480~250 km 的位移[40] [41] [42]。

喀什–叶城转换体系具有右行走滑的特性，将塔里木盆地与帕米尔东北缘分隔，由几条右行挤压转换断层组成，自西向东依次为：阿尔塔什、叶尔羌、库木塔格和红其拉甫断裂[27] [43]。喀什–叶城转换体系

分别在 37 Ma 和 25~18 Ma 发生活动[6] [43]，自~20 Ma 开始出现走滑挤压过程，引起帕米尔东北缘逆冲断裂上盘的快速隆升[27]；从~12 Ma 经历了持续的走滑挤压过程，在~5 Ma 以后开始逐渐减速[44] [45] [46]。

恰曼走滑断裂带位于在印度板块西侧，南端连接了麦克兰增生汇聚带，其北侧则连接喜马拉雅汇聚带，南北长~1000 km，东西宽 30~20 km [47] [48]。恰曼断裂从 45 Ma 开始走滑，到晚渐新世以来向北位移了至少 200 km 的距离，南端引起了麦克兰增生楔的发育，北端则带动帕米尔突刺移动[49]。

阿尔金左行走滑断裂自藏北的拉竹龙向北东方向延伸，经阿克塞、党河、疏勒河至甘肃的玉门镇一带，长~1600 km [50]。从断裂带总的展布形态来看，主要表现为拉长的 S 型，说明带本身后期虽然以走滑运动为主，但仍带有一定成分的挤压性质[51]。阿尔金走滑断裂带西南段自~49 Ma 开始活动。从晚始新世(37 Ma)到晚中新世，阿尔金走滑断裂在南西端引起的地形变形主要由康西瓦左行走滑断裂和北倾的甜水海逆冲断裂吸收[52]。同时，其东北端的位移则主要通过党河南山和祁连山逆冲断裂所吸收。在晚渐新世到中中新世，阿尔金走滑断裂迁移到肃北段，并截切了党河南山、野马山、中祁连山和北祁连山山前逆冲断裂带[19] [20] [21]。

3. 研究方法和数据来源

3.1. 研究方法

盆山耦合的思想认为造山带逆冲推覆作用产生的构造负载是前陆盆地发育发展的主要因素，加速了前陆盆地发生沉降的速率同时产生可容忍空间容纳更多的构造卸载[53]。造山带和盆地是两个最基本的大陆构造单元，是地壳运动的两种显著不同但又密不可分的表现结果。造山带为盆地提供了大量的碎屑物质，而盆地则对其构造演化及与周围环境相互作用的信息很好的保存。在新生代时期，新构造运动表现较为强烈的地区，对造山带的基岩的低温热年代学分析，同时结合靠近造山带的盆地中的碎屑沉积物的沉积相、碎屑颗粒的低温热年代学研究，可以知道造山带长时间尺度的演化过程。

3.2. 数据来源

新生代以来，印度板块向北俯冲导致了上千公里的地壳缩短，板块侧向移动，逆冲断裂所引起的地壳增厚等地质过程。对于印度板块与欧亚大陆发生碰撞的远程效应何时传递到青藏高原北部一直是国内外研究者所热衷的研究领域，因此积累了大量的有关低温热年代学、沉积相分析、古地磁磁性地层、地球化学等方面的研究结果(图 3，表 1)。

Table 1. Record of tectonic activities from the northern Tibetan Plateau from east to west
表 1. 新近纪早期青藏高原北缘自东到西构造活动记录

研究地点	时间(Ma)	研究方法	数据来源
(1) 北祁连	13.0	沉积学	[54]
(2) 北祁连	20~10	磷灰石裂变径迹	[55]
(3) 北祁连	13.0	沉积学、锆石 U-Pb	[56]
(4) 北祁连	10.0	磷灰石(U-Th)/He	[57]
(5) 北祁连	13.0	沉积学、锆石 U-Pb	[15]
(6) 中祁连	12.0	磷灰石(U-Th)/He	[58]
(7) 中祁连	16.9	磷灰石裂变径迹	[59]
(8) 中祁连	15.4	磷灰石裂变径迹	[60]
(9) 南祁连	16.7、15.8	磷灰石裂变径迹	[61]

Continued

(10) 南祁连	14.7	古地磁和沉积学	[35]
(11) 南祁连	12.0	古地磁和沉积学	[62]
(12) 柴达木	17.9	磷灰石(U-Th)/He	[63]
(13) 东昆仑	16.3	锆石和磷灰石裂变径迹	[64]
(14) 东昆仑	17.0、12.9	磷灰石(U-Th)/He	[65]
(15) 东昆仑	14.9	沉积学	[66]
(16) 东昆仑	17.0	古生物	[67]
(17) 东昆仑	17.3	磷灰石裂变径迹	[59]
(18) 阿尔金	17.2、15.7	磷灰石裂变径迹	[68]
(19) 阿尔金	19.5	磷灰石裂变径迹	[69]
(20) 阿尔金	17.6	磷灰石裂变径迹	[59]
(21) 阿尔金	13.8	磷灰石裂变径迹	[70]
(22) 阿尔金	16.9、15.2	磷灰石裂变径迹	[71]
(23) 阿尔金	15.2	磷灰石裂变径迹	[72]
(24) 阿尔金	16.0	古地磁和沉积学	[73]
(25) 阿尔金	17.0、14.0	磷灰石裂变径迹	[34]
(26) 西昆仑	22.0、17.0	锆石和磷灰石裂变径迹	[74]
(27) 西昆仑	20.0	云母 $^{40}Ar/^{39}Ar$	[75]
(28) 西昆仑	20.5、18.0	磷灰石裂变径迹	[11]
(29) 西昆仑	14.0	磷灰石裂变径迹	[76]
(30) 西昆仑	15.0	沉积学和地震解译	[77]
(31) 西昆仑	20.0	古地磁和沉积学	[78]
(32) 西昆仑	17.0	沉积学和地球化学	[79]
(33) 西昆仑	15.0	锆石裂变径迹	[9]
(34) 帕米尔	20.0、13.0	磷灰石裂变径迹	[27]
(35) 帕米尔	15.7	锆石 U-Pb	[80]
(36) 帕米尔	20.0、15.0	磷灰石裂变径迹	[81]
(37) 帕米尔	16.0	磷灰石(U-Th)/He	[82]
(38) 帕米尔	14.8	锆石(U-Th)/He	[46]
(39) 帕米尔	13.0、12.4	锆石(U-Th)/He	[45]
(40) 帕米尔	18.5、16.6	磷灰石裂变径迹	[83]
(41) 帕米尔	~13.0	磷灰石裂变径迹	[84]
(42) 帕米尔	15.0	磷灰石裂变径迹	[85]

4. 新近纪早期构造隆升

在青藏高原北部，沿兴都库什山－帕米尔高原北缘－西昆仑山－阿尔金山－北祁连山一线有诸多的低温热年代学和沉积学的研究结果报道。

4.1. 低温热年代学记录

北祁连山南侧的基岩磷灰石裂变径迹结果表明逆冲断裂带的活动引起的快速冷却的时间出现在20~10 Ma [55] [57]。在南祁连山和北柴达木地块山前的逆冲断裂带的上盘中的磷灰石裂变径迹和(U-Th)/He年龄记录了山体快速隆升的时间发生在中中新世[61] [63]。锆石和磷灰石裂变径迹和(U-Th)/He年龄反映了东昆仑山脉在17~16.3 Ma出现一期快速隆升过程[64] [65]。阿尔金山江尕勒萨依剖面的磷灰石裂变径迹和(U-Th)/He年龄揭示了快速隆升出现在17~15 Ma [68] [72] [73]。鲸鱼湖剖面的磷灰石裂变径迹结果表明祁漫塔格山脉在~17 Ma发生快速隆升[86]。

西昆仑山脉自西侧的库地到东侧的普鲁，基岩锆石和磷灰石裂变径迹和云母 $^{40}Ar/^{39}Ar$ 年龄集中在22~12.3 Ma [11] [74] [75]。碎屑磷灰石裂变径迹年龄结果表明，在帕米尔高原东北缘的奥依塔格地区的主帕米尔逆冲断裂发生活动是时间是~20 Ma，并导致沉积剖面的沉积物物源发生改变，开始以近缘的山前堆积为主[27] [87]。叶尔羌河谷中靠近库克走滑断裂基岩中的锆石(U-Th)/He年龄为14.8 Ma，代表了后期的快速隆升的时间[46]。西南天山乌恰地区的中生代地层的碎屑磷灰石裂变径迹发生完全退火后的冷却年龄为18.5 Ma和16.6 Ma，代表了山前逆冲断裂向塔西南盆地内部迁移的活动时间[83]。帕米尔突刺西南端靠近塔吉克盆地的侏罗系到白垩系地层的砂岩部分退火的磷灰石裂变径迹年龄集中在~13 Ma [84]。西南天山最西端的吉萨尔山脉南坡的逆冲褶皱带内的完全退火的磷灰石裂变径迹和(U-Th)/He年龄集中在~12 Ma；在塔吉克盆地中部的Kurgan剖面，由逆冲褶皱引起的地层发生强烈部分退火的时间在17.2 Ma [32]。

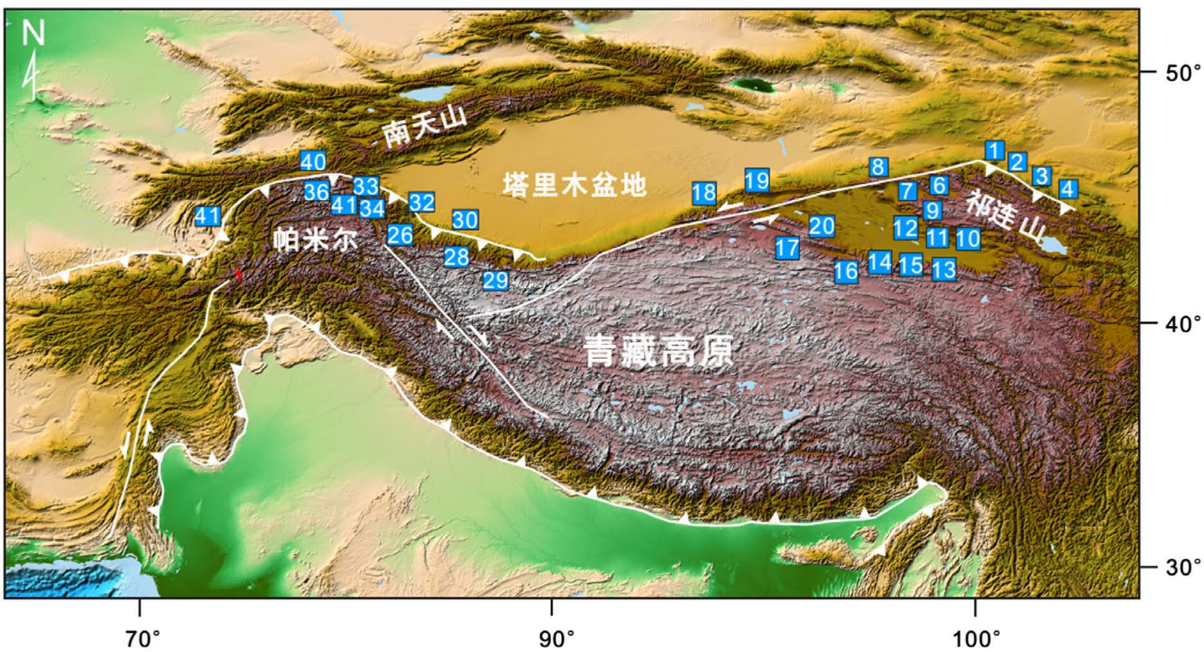

Figure 3. Map of studying location about the low temperature thermochronology from the northern Tibetan Plateau, and the blue numbers are corresponding to Table 1

图3. 青藏高原北缘部分低温热年代学研究结果位置图，其中蓝色数字与表1中数字对应

4.2. 沉积学记录

北祁连山北坡的石油沟剖面和酒西盆地老君庙剖面的沉积物的粒度粗转变、不整合面和沉积速率的变化出现在~13 Ma，指示了北祁连山的快速隆升[54] [56] (图4)。柴达木盆地东北缘的怀头他拉和大红沟剖面的沉积相变粗、沉积速率加快出现在~14.7~12.0 Ma，证明了南祁连山在中中新世发生了快速的隆升[35] [62]。

柴达木盆地西南侧的晚始新世沉积地层中的地震剖面的解译结果表明，祁漫塔格地块在早中新世经历了南西–北东向的挤压过程，出现快速隆升过程[88]。阿尔金山江尕勒萨伊剖面，新生代地层的古地磁年龄和沉积学的结果表明阿尔山发生快速隆升的时间在~16 Ma [73]。此外，在中中新世，沉积剖面中出现砾岩堆积速率显著加快的现象可以在米兰河剖面[72]、索尔库里盆地[89]、阿克塞盆地[89]和肃北盆地[10] [90]看到。

位于西昆仑山脉北坡的柯克亚剖面，从晚渐新世到中中新世(~15 Ma) 出现沉积速率加快、沉积相由细变粗的现象，结合区域内的构造活动反映了铁克里克逆冲断裂的活动引起西昆仑山脉的快速隆，反映了青藏高原西北缘进入强烈的挤压构造环境中[9]。西昆仑山脉北坡的齐木根剖面的粘土矿物分析结果表明自 17 Ma 开始，由于西昆仑山脉发生快速隆升，引起了地势增高，导致了化学风化速率的下降，物源发生变化[79]。帕米尔高原北侧的阿莱谷地在~16.4 Ma 开始出现地壳缩短，并一直持续到现今，伴随着Massaget 组粗粒砾岩层的出现[91]。西南天山山前乌恰地区的铁热克萨孜剖面的古地磁磁性和沉积相分析结果表明，在 22.1~12 Ma 出现显著的沉积速率加快和沉积粒度变粗的现象，代表了塔里木盆地基底向北快速俯冲的时间[92]。

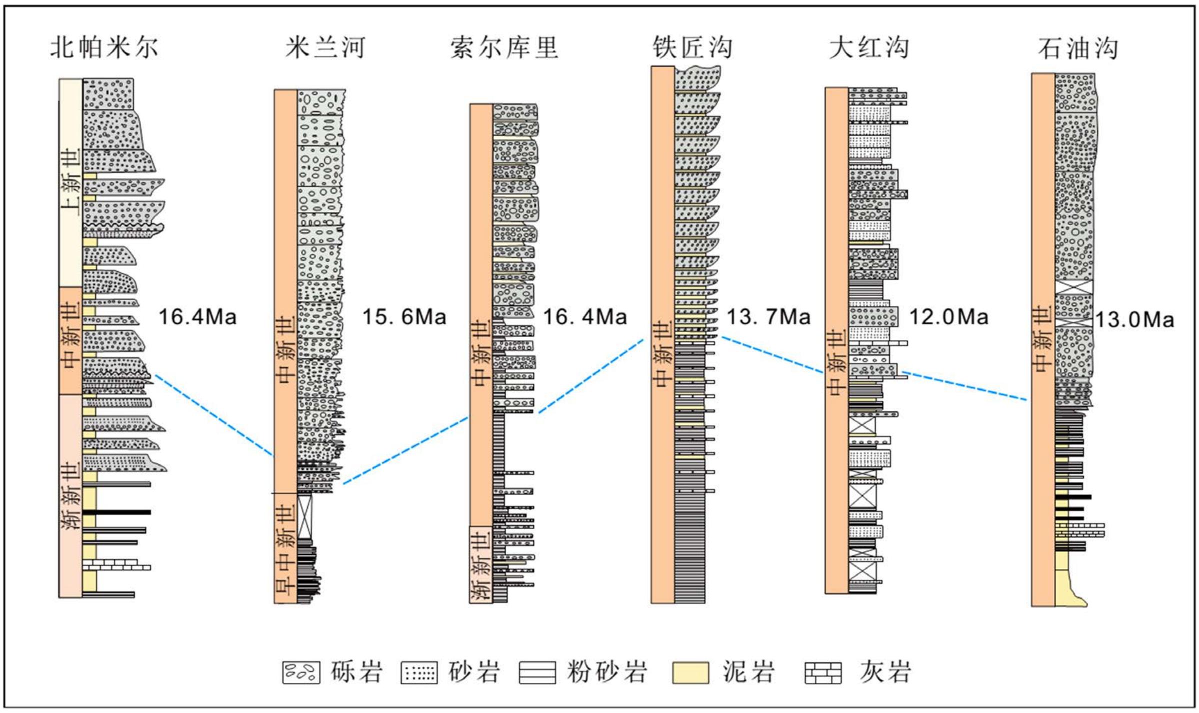

Figure 4. Lithostratigraphic correlations between six sedimentary sections along the northern Tibetan Plateau, including the north Pamir [83], Miran River locality [72], Xorkol Basin [89], Tiejianggou [10], Dahonggou [62], and Shiyougou [56], respectively

图 4. **青藏高原北缘新生代沉积剖面，从右到左剖面地点依次是北帕米尔**[83]、**米兰河**[72]、**索尔库里**[89]、**铁匠沟**[10]、**大红沟**[62]**和石油沟**[56]

5. 新近纪早期青藏高原北缘地壳变形吸收方式

晚渐新世到早中新世(25~18 Ma)，帕米尔突刺在东西两侧的喀什–叶城转换体系、喀喇昆仑和恰曼走滑断裂的活动下向北推进，驱动了主帕米尔逆冲断裂的活动，引起了塔吉克(22 Ma)和塔西南盆地(~23~20 Ma)发生快速沉降[8] [29] [43]。在南、南东方向上，塔里木盆地基底向西昆仑–青藏高原下俯冲，驱动了山前逆冲断裂带的活动(22~18 Ma)，塔西南坳陷进入快速沉降时期，同时西昆仑和阿尔金山发生快速隆升[19] [22] [26] [34] [68]。

晚渐新世到中中新世是阿尔金走滑断裂快速活动的时期，青藏高原在其带动下向北东方向移动的同时受到了塔里木盆地基底东南部的俯冲挤压，因而导致阿尔金山的快速隆升，柴达木盆地成为完全封闭的盆地[6] [38] [93]。阿尔金走滑断裂在祁漫塔格西端形成了左行右阶展布样式，汇入到山脉南侧形成的一系列的逆冲－褶皱转换挤压区域，成为祁漫塔格山发生隆升的主要驱动力[37] [68]。柴达木盆地基底同时受到南侧的东昆仑山脉和北东侧的南祁连山的夹持，向南俯冲到东昆仑山脉之下[21] [37]。于此同时，祁连地块受到阿拉善－鄂尔多斯基底的向南西方向的俯冲[94]，地表则出现了一系列北西－南东方向平行分布的山脉，自东昆仑山到北祁连山在 20~10 Ma 发生了一期快速隆升构造过程[55] [57]。

如果党河南山与北祁连山之间的地壳缩短达到了~150~66 km 是正确的话[21] [95]，考虑到帕米尔突刺向北移动的过程中地壳缩短的距离为 300 km [96]；西侧塔吉克－塔里木盆地基底向帕米尔的俯冲深度超高了柴达木盆地基底向南俯冲的深度。那么在青藏高原西北缘主要通过陆内俯冲占主导作用，辅以大型走滑断裂的移动来吸收和调节地形变形，而在东北端，主要依靠阿尔金走滑断裂的迁移发生的侧向移动，同时驱动的陆内俯冲作用引起的地壳增厚、缩短过程来完成(图 5)。

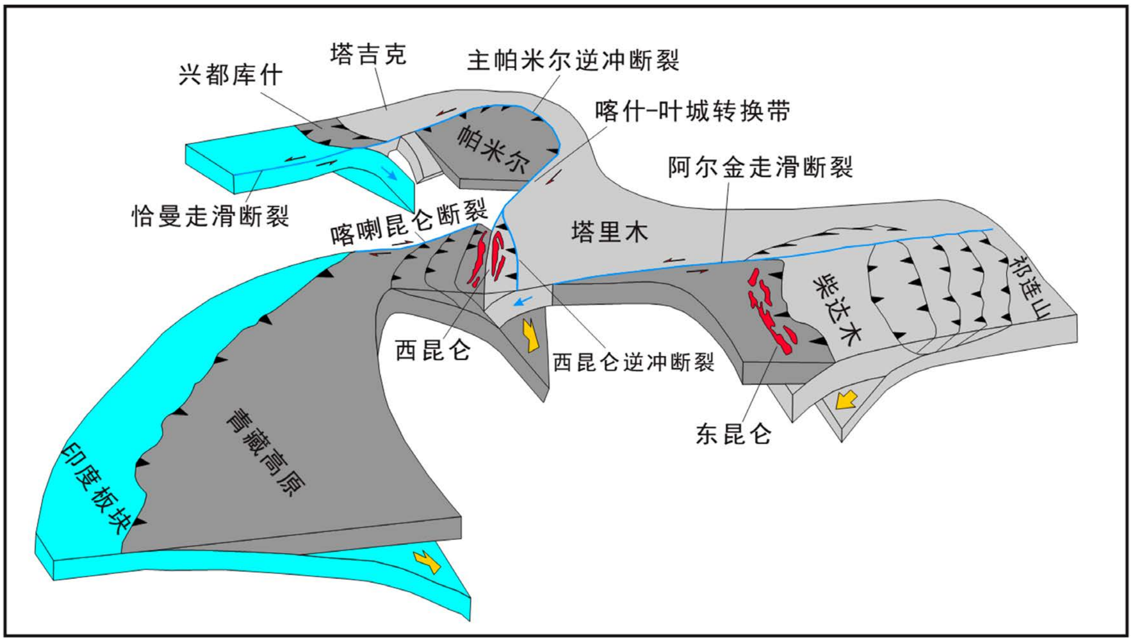

Figure 5. Diagrams showing major structures within the northern Tibetan Plateau [52]
图 5. 青藏高原北缘构造演化示意图[52]

6. 结论

通过对青藏高原北缘的低温热年代学、沉积学的研究结果的梳理，结合区域内盆地沉降、大型逆冲和走滑断裂的活动时间，可以发现青藏高原北缘在早－中中新世经历了快速的隆升过程。在高原西北缘主要通过陆内地壳缩短、塔吉克－塔里木盆地基底向南深俯冲、主帕米尔－喀喇昆仑－喀什叶城转换体系的活动来吸收和调节地形变形；在东北端，主要依靠阿尔金走滑断裂的迁移发生的侧向移动，引起的陆内俯冲作用、地壳缩短过程来实现。青藏高原北部的地质框架在新近纪早期开始建立。

青藏高原北缘，远离印度与欧亚大陆发生直接碰撞的部位，从盆山耦合的思路去追溯碰撞的远程效应在高原北缘的体现是有效的，但是由于这一地质过程的进行及其复杂，因而今后的研究在基于这一研究思路的基础上，应开展综合的、系统的研究，对上述问题进一步厘定。

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