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塔中隆起NNE向走滑断裂特征及形成机制

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提要:为了确定塔中隆起NNE向走滑断裂特征及形成机制,利用构造要素相关性分析及构造解析方法,通过对二维和三维资料的解释,揭示了走滑断裂的构造变形特征,确定了走滑断裂的形成机制。NNE向走滑断裂在地震剖面上表现为压扭和张扭在垂向上叠加的特点,其形成演化主要经历了中奥陶世末压扭和晚志留世—中泥盆世张扭两个阶段。先存基底软弱带和塔里木板块周缘造山带的演化共同控制了这套走滑断裂的形成。中奥陶世末,塔里木板块南缘洋盆俯冲闭合产生的近南北向挤压应力斜向作用于NNE向的基底软弱带之上,导致断裂上部地层被撕裂产生走滑分量,从而形成了北东向的左旋走滑断裂系统,同时,来自塔里木板块西北缘的挤压应力垂向作用于走滑断裂上,导致NNE向走滑断裂发生压扭变形。晚志留世—中泥盆世,塔里木板块南缘的挤压应力继续斜向作用于NNE向走滑断裂之上导致其继续发生走滑变形,同时,来自塔里木盆地西北缘的NW向伸展应力垂向作用于走滑断裂上,导致NNE向走滑断裂发生张扭变形。

关 键 词:塔中隆起;断裂体系;走滑断裂;雁列式断层;形成机制

中图分类号:P542^{+}.3 **文献标志码**:A **文章编号**:1000−3657(2016)05−1569−10

Deformation characteristics and formation mechanism of NNE−trending strike−slip faults in Tazhong Uplift

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Abstract: In this study, the correlation method of structural factors and structural analysis were used to determine the formation mechanism of NNE−trending strike−slip faults in the Tazhong Uplift. The interpretation of 2D and 3D seismic data revealed deformation characteristics of the NNE−striking faults and determined their formation mechanism. NNE−trending strike−slip faults exhibit vertical superposition of compresso−shear faults and tenso−shear faults in seismic profiles. They have experienced two

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stages of activities: the late Ordovician compresso−shear faulting and the late Silurian−middle Devonian tenso−shear faulting. The formation of the NNE−trending strike−slip faults was controlled by the pre−existing basement weak zone and the evolution of the orogenic belts around Tarim plate. At the end of Middle Ordovician, a NS− trending compressive stress was generated by the subduction and closure of the ocean basin on the south margin of Tarim plate, and it acted on the NE−trending basement weak zone, resulting in the formation of NNE−trending strike−slip faults. Meanwhile, the compressive stress from the northwest margin of Tarim plate vertically acted on the NNE−striking strike−slip fault, leading to the compresso−shear deformation. In late Silurian−middle Devonian period, the NS− trending compressive stress continually acted on the strike− slip faults, resulting in continued strike−slip deformation. Moreover, the extensional stress from the northwest margin of Tarim plate vertically acted on the NNE−striking strike−slip fault, leading to the tenso−shar deformation.

Key words：Tazhong uplift; fault system; strike−slip fault; en−echelon faults; formation mechanism

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1 引 言

塔里木盆地塔中低凸起为一早古生代古隆起，后期又经历了多期构造调整，构造变形复杂。除了塔中I号断裂带、塔中II号断裂带等NW向展布的逆冲断裂之外，最新的二维和三维资料显示在塔中隆起及其北部围斜区发育一系列NNE向走滑断裂。多位学者对这一系列走滑断裂的活动时间和形成机制开展过研究工作，并取得了许多成果：(1)走滑断裂主要活动期为中晚奥陶世、志留纪晚期、中泥盆世末[1−7]；(2)塔中隆起北坡雁列式张性正断层的形成与昆仑山早古生代碰撞造山之后的应力松弛有关[8]；(3)盆地西南缘或东南缘挤压应力对基底NE向先存基底构造会产生走滑分量，从而形成了NE向的左旋走滑断裂系统[6−7,9−10]。但是前人的模式无法解释为什么塔中隆起及其北坡发育的大量张扭性走滑断裂，另外也无法解释NNE向走滑断裂在垂向上发生了压扭−张扭的反转，NNE向走滑断裂形成机制是什么？形成过程是怎样的？仍然需要进一步的研究。本次研究在参考前人研究的基础上，利用塔中最近几年采集和处理的地震资料，结合现有钻井数据，开展精细构造解析，并结合盆地周缘造山带的演化，确定了塔中地区NNE向走滑断裂的形成过程和形成机制。

2 区域地质概况及基础资料

2.1 区域地质概况

塔中隆起位于塔里木盆地中部的塔克拉玛干沙漠腹地，在构造上位于塔里木盆地中央隆起带中段(图1−a)，呈NW−SE方向展布，北靠满加尔坳陷，西接阿瓦堤坳陷和巴楚断隆，向南沿斜坡过渡到塘古孜巴斯坳陷。

塔中地区地层发育较全，除缺失侏罗系外，从前震旦系基底到第四系均有出露。前震旦系基底主要由太古宙、古元古代深变质岩系，以及中、新元古代中、浅变质岩系组成；震旦系是塔里木盆地基底形成以来的第一套沉积盖层，在塔中隆起带北部的满加尔坳陷向南超覆尖灭；上震旦统—奥陶系为海相碳酸盐岩沉积；志留−二叠系为海陆交互相沉积；三叠−第四系为陆相沉积[11]。塔中隆起带现今结构具有明显的双层构造特征：下层寒武—奥陶系海相碳酸盐岩为断裂控制的复式背斜隆起，表现为以北西向的塔中I号断裂带为主干断裂，其南侧的北西向断裂和近东西向断裂与之组成向西撒开、向东收敛的帚状构造；上层碎屑岩地层内断裂不发育，结构简单，志留系—石炭系表现为东南高、西北低的宽缓大斜坡，塔中隆起带南部断裂核部地区缺失志留系—泥盆系(图1−b)。塔中地区石炭系以上地层明显表现为西低东高的向北西倾没的平缓斜坡，只有局部地区可见少量断裂切穿石炭系，但是均未切穿二叠系及其以上地层，向东与塔东隆起带连为一体。

2.2 基础资料

为了确定塔中隆起NEE向走滑断裂的特征，本文收集了中国石化西北油田分公司最近几年在塔中隆起采集、处理的三维地震资料，分别是2006年的卡1三维区地震资料，2010年的顺北三维区地震

资料和2013年的顺南三维区地震资料。在典型钻井（中1井、顺1井、顺9井、顺南4、顺南5、顺南7等）层位标定的基础上，对典型地震剖面进行了解释。此外还引用了文献[4]中塔中82井区的地震剖面。三维区、钻井和地震剖面位置见图1。

3　走滑断裂的几何学特征

在塔中隆起北坡，发育一系列NNE向的走滑断裂，这些断裂与控制塔中隆起的NW向主断裂带在平面上近直交，形成了塔中隆起的网格状断裂系统（图1）。通过对二维和三维地震资料的解释，在塔中隆起及其北坡发现了至少15组NNE向走滑断裂，在二维地震剖面上主干断裂表现为高角度近似直立断面，向下直插入基底，向上断至石炭系底，垂向断距不大，大多数仅仅表现为同相轴的在纵向上的一致性完全（图2）。在新的三维地震剖面上，走滑断裂带倾角很大，断面上缓下陡，与一般正断层、逆冲断层所显示的上陡下缓的产状特征相反，断裂在中—下奥陶统收敛为一条主断裂直插基底，在上奥陶统上部开始呈花状撒开（图3，图4）。在平面上，扭应力的存在会使沿走滑断裂形成一系列的雁列式构造，在顺北三维区，由于扭应力自深部基底向浅部盖层发散传递，在上奥陶统上部—中泥盆统形成了NNW向雁列展布的断层系统，这组破裂表现为与主位移带大角度相交的、延伸不长的正断层组（图3-a，b）。另外，走滑断裂主位移带一端常常

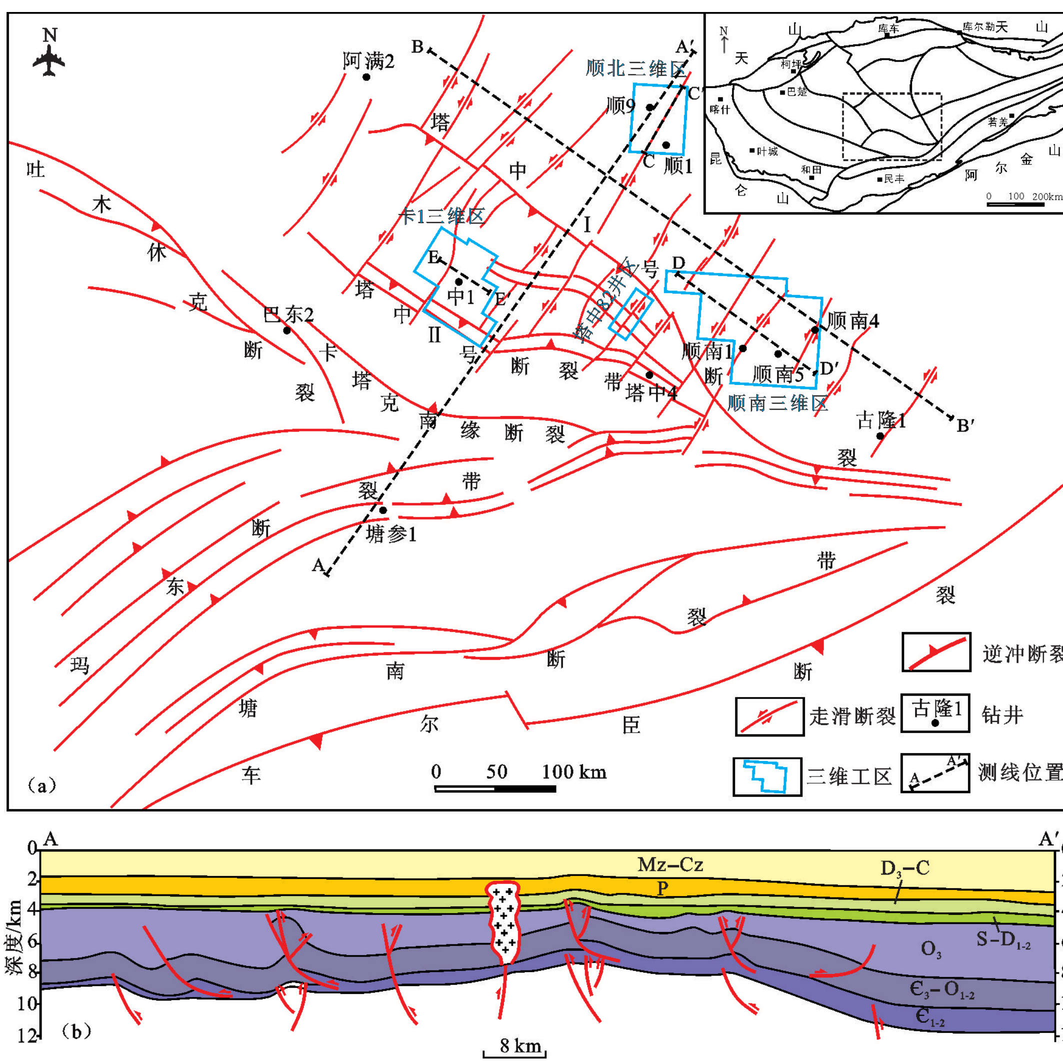

图1　塔中隆起断裂分布图（a）和地质剖面（b）

Fig.1　Fault distribution（a）and geological section（b）of Tazhong uplift，Tarim Basin

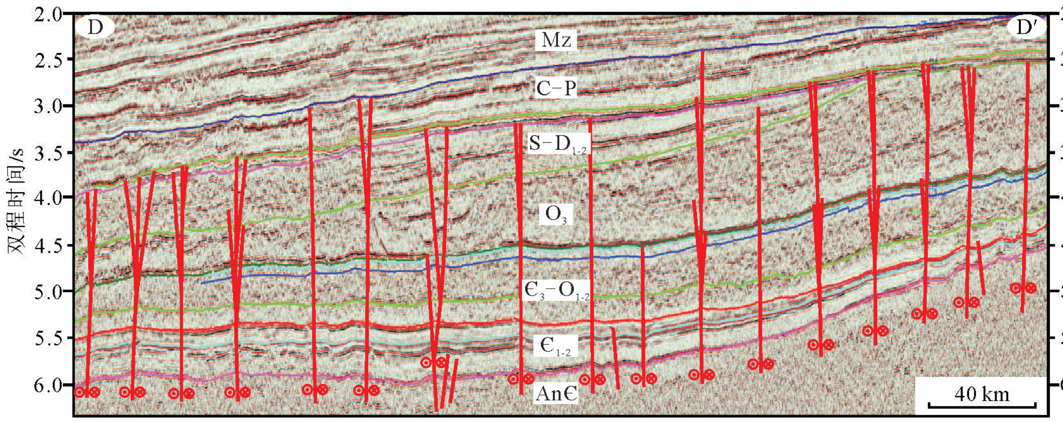

图2 塔中隆起北坡走滑断裂的二维地震剖面(剖面位置见图1)

Fig.2 2D seismic section of strike-slip fault on the northern slope of Tazhong Uplift

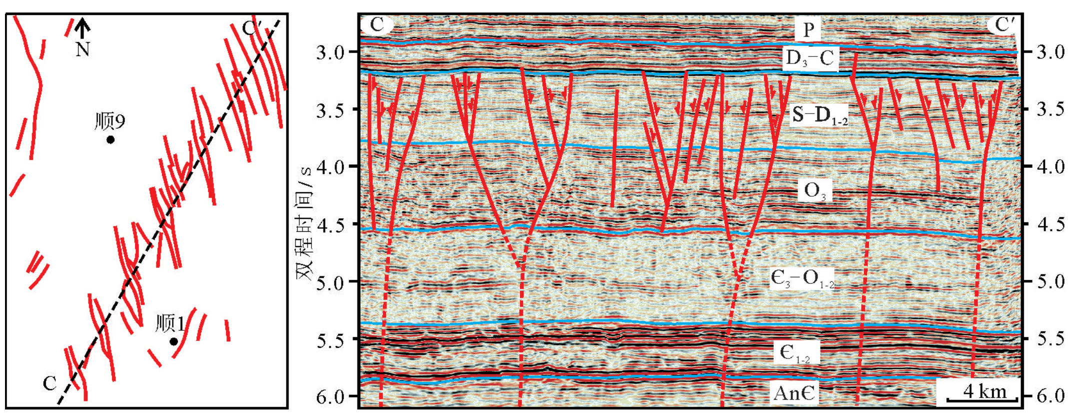

图3 塔中隆起北坡顺北三维区雁列式断层平面展布(左)和地震剖面(右)(顺北三维区位置见图1)

Fig.3 Distribution map and 3D seismic section of en-echelon faults in Shunbei 3D area, northern slope of Tazhong Uplift

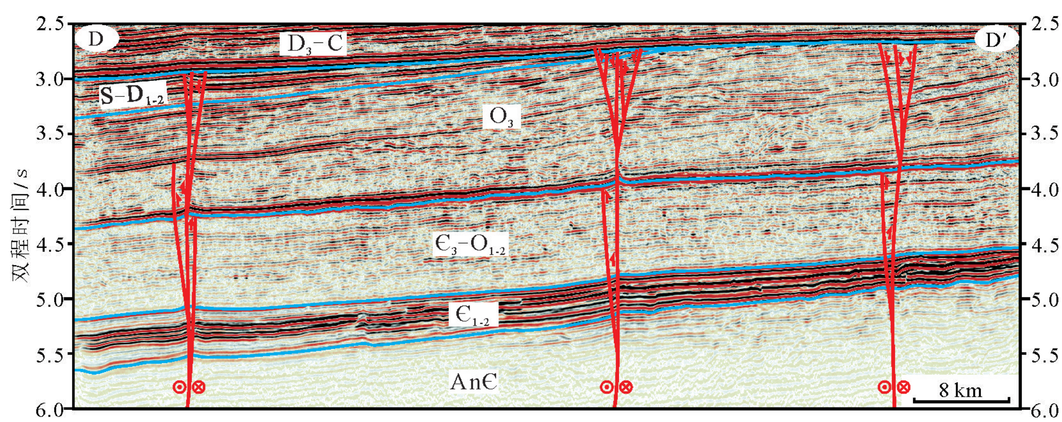

图4 塔中隆起北坡顺南三维区走滑断裂的地震剖面(剖面位置见图1)

Fig.4 3D Seismic section of strike-slip fault in Shunnan 3D area, northern slope of Tazhong Uplift

会分化成马尾状断裂,并沿走向逐渐消失。在顺南1井、顺南4井等多条走滑断裂带端部均表现出发散的马尾状断裂组合[7]。

这些走滑断裂的性质在塔中隆起和顺托果勒地区又表现出一定的差异。塔中地区"负花状构造"发育[5,12]。在地震剖面上,主断面陡立,向下断穿寒武系至基底,向上多断至志留系—泥盆系,西部少量断至二叠系。主干断裂在上奥陶统—中泥盆统内部形成2条或多条分支断裂,向上撒开,形成反向下掉的断堑,向下收敛、合并,具有明显的"拉张、正断、向形"的负花状构造特征(图5,图6)。塔中北坡顺托果勒地区的走滑断裂带在垂向上不同层位表现出明显的性质差异:在中—下奥陶统顶部表现为具有"挤压、逆断、断垒"特征的正花状构造样式,而在上奥陶统顶部—中下泥盆统表现为具有"拉张、正断、断堑"特征的负花状构造样式,主干断裂及其伴生的分支断裂构成了"Y"和反"Y"字型的剖面组合样式(图3)。

4　走滑断裂的活动期次

二维和三维地震资料的综合解释显示,在地震剖面上,断裂断穿层位的特征可以显示为以下4种类型:①断裂向下断入前寒武系基底,向上断穿中奥陶统顶面,并向上消失在上奥陶统厚层泥岩中,错断的层位主要显示为逆冲的特征;②断裂向下断入前寒武系基底,向上断至中泥盆统顶面,在中奥陶统顶部表现为"逆断、断垒"的特征,在上奥陶统顶部—中下泥盆统表现为"正断、断堑"的特征;③自基底向上断穿至中寒武统顶面,并且在从中奥陶统顶面向上都表现为"正断、断堑"的特征;④上述第②和③断裂在少数地区向上断入石炭—二叠系。

从上述断裂断穿层位及发育特征判断,塔中隆起及其北坡走滑断裂的发育主要经历了中奥陶世末压扭和志留纪—中泥盆世张扭2个阶段,在石炭—二叠纪仅仅经历了微弱的调整改造,可能与当时的岩浆活动有关,因此本文未将石炭—二叠纪作为走滑断裂活动的关键阶段来考虑。

5　走滑断裂的形成机制

5.1 构造背景

奥陶纪—中泥盆世是塔里木盆地构造演化的一个重要的构造转换期。塔里木盆地周缘的洋盆的拉张伸展、俯冲闭合及之后的碰撞造山均对盆地内构造变形产生了一定的影响。

(1)西昆仑造山带

塔里木板块西南缘的昆仑洋从中奥陶世开始向南部中昆仑地体俯冲消减,并最终在志留纪闭合,中昆仑岛弧与塔里木大陆板块碰撞[14−19]。碰撞造山作用一直持续到晚中泥盆世末,造成库地缝合带北缘的塔南地区形成了周缘前陆褶皱冲断带和周缘前陆盆地[20]。塔中地区由于受到自南西向北东的挤压应力的影响,形成规模巨大的NW向逆冲断裂带[4,21−23]。

(2)阿尔金造山带

塔里木板块东南缘的阿尔金洋在中奥陶世—志留纪经历了洋壳闭合、活动陆缘增生、弧/陆碰撞、陆陆碰撞和陆壳深俯冲过程[24−27]。强烈的碰撞造山运动造成塘古巴斯坳陷及塔东南地区都发生了强烈的断裂活动,车尔臣深断裂该时期以逆冲活动为主,兼有一定的走滑性质,在塘古巴斯坳陷,则形成了向NW凸出的弧形断裂系[22,28]。

(3)南天山造山带

塔里木板块北缘的南天山造山带在古生代经历了复杂的构造演化与地壳增生过程[29−35]。分割塔里木板块和哈萨克—伊犁—中天山地块之间的南天山洋新元古代晚期—寒武纪,从中奥陶世晚期开始闭合。在南天山洋俯冲闭合的环境下,先前的研究者对塔里木盆地北缘志留纪—中泥盆世的构造环境的认识出现了分歧:①一些学者基于构造分析的研究方法,认为南天山洋在该时期一直都是向北俯冲并最终闭合,塔里木北缘一直为被动大陆边缘,而洋盆北缘的伊犁—中天山地块南缘则为活动大陆边缘[36−41];②而另一些学者对南天山地区的冲断岩片和侵入岩的岩石地球化学研究显示,塔里木北缘在该时期已由被动陆缘转化为主动陆缘,并形成了一系列东西向分布的花岗质侵入岩,南天山古洋盆存在南北双向同时俯冲的阶段[42−49]。

最近有研究者发现南天山洋南缘在中奥陶世晚期—早石炭世先后经历了主动陆缘环境和被动陆缘环境:①南天山洋从中奥陶世晚期开始俯冲闭合,闭合通过洋壳向南俯冲到塔里木板块之下来实现,洋盆的俯冲闭合导致塔里木板块北缘处于区域

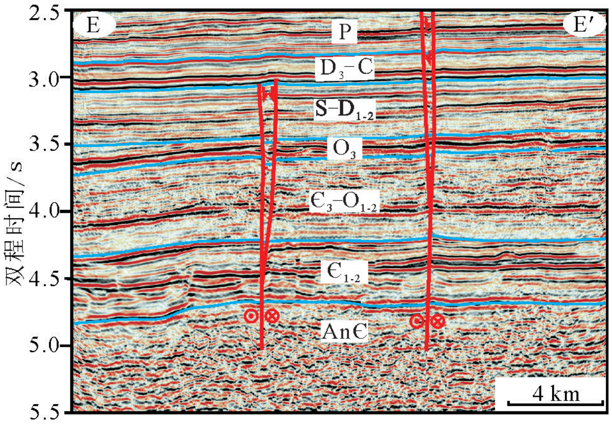

图5 卡1三维区走滑断裂的地震剖面(卡1三维区位置见图1)
Fig.5 3D seismic section of strike–slip fault in Ka 1 3D area, Tazhong Uplift

挤压的构造环境;②晚志留世—早石炭世,由于南天山弧后盆地的形成,塔里木板块北缘处于区域伸展的构造环境[32–35]。

5.2 基底软弱带

前人研究发现,塔里木盆地北纬40°附近分布有一条东西向的正磁异常带,塔中地区位于该异常带之南,由近北东向相间的正负磁异常带构成,这种近北东向相间的正负航磁异常带可能代表了塔中存在北东向的隐伏基底断裂。该隐伏基底断裂作为构造薄弱带,在后期区域应力场作用下容易沿基底产生破裂,这可能是塔中地区大规模北东向走滑断裂发育的基础[50–51]。

5.3 形成模式

(1)中奥陶世压扭断裂的形成模式

从中奥陶世开始,塔里木板块西南缘的古昆仑洋、东南缘的阿尔金洋和北侧的南天山洋相继进入俯冲阶段,塔里木板块处于南北两侧双向挤压的构造环境。

古昆仑洋、阿尔金洋的俯冲闭合导致在塔里木盆地南缘形成了两套断裂系统:受控于西昆仑造山带的塔中NW向帚状断裂系和受控于阿尔金造山带的塘古巴斯坳陷NEE向弧形断裂系。两套断裂系统在平面上斜交,从交切关系上可以判断NEE向弧形断裂系形成时间略晚于NW向帚状断裂系。来自

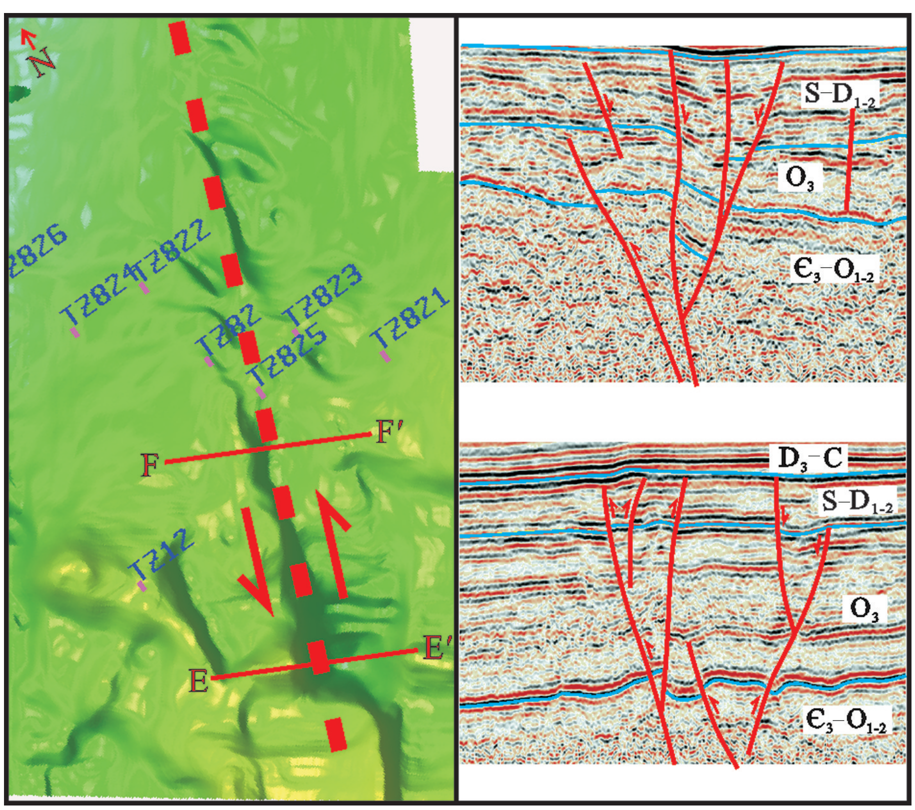

图6 塔中82井区奥陶系碳酸盐岩顶面立体图与地震剖面(据文献[13]修改)
(塔中82井三维区位置见图1)
Fig.6 Structural map and seismic section of Ordovician carbonate in TZ82 strike–slip fault, Tazhong uplift

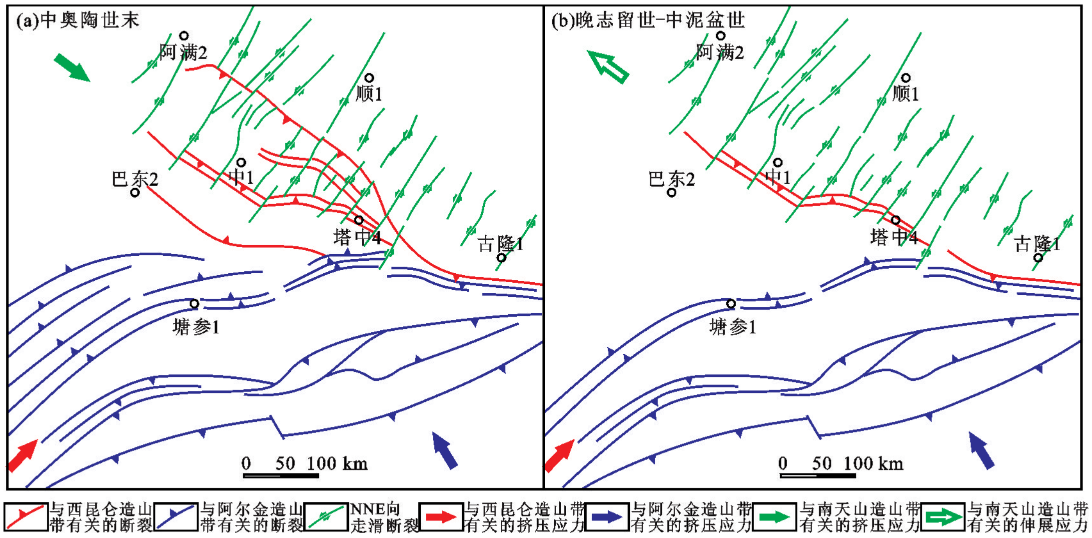

图7 塔中隆起NNE向走滑断裂压扭变形和张扭变形的动力学背景

Fig.7 Dynamic background of compresso-shear deformation and tenso-shear deformation of the NNE-trending strike-slip faults, Tazhong Uplift

阿尔金造山带的挤压应力通过NEE向弧形断裂传递到塔中隆起，斜向作用于NNE向的基底软弱带之上，导致断裂上部地层被撕裂产生走滑分量，从而形成了北东向的左旋走滑断裂系统（图7-a）。同时，塔里木板块北缘南天山洋（特别是西南天山洋）俯冲消减所产生的向NW向南东的挤压应力近垂直向作用于走滑断裂上，导致主断裂带在中—下奥陶统顶部表现为正花状的构造变形特征（图7-a）。

（2）晚志留世—中泥盆世张扭断裂的形成模式

晚志留世—中泥盆世，塔里木地块南侧仍为挤压体制，塔中NW向帚状断裂系和塘古巴斯坳陷NEE向弧形断裂系继承性活动。由于南天山弧后盆地的形成，塔里木板块北缘为被动陆缘环境，盆地西北缘志留纪被动陆缘沉积和盆地内部志留纪—中泥盆世发育的正断层均反映了这期区域伸展[8,52-53]。在这种南压北张的构造环境下，先前已经形成走滑断裂发生继承性活动和调整改造，一方面来自阿尔金造山带的挤压应力继续斜向作用于NNE向走滑断裂之上，另一方面受南天山洋（特别是西南天山洋）弧后裂谷作用产生的NW向伸展应力近垂向作用于走滑断裂上，导致主断裂带在上奥陶统顶部—中下泥盆统表现为负花状的构造变形特征（图7-b）。

6 结 论

（1）塔中隆起及其北坡走滑断裂发育，在地震剖面上表现为压扭和张扭在垂向上叠加的特点，其形成演化主要经历了中奥陶世末压扭和晚志留世—中泥盆世张扭2个阶段。

（2）中奥陶世末，来自阿尔金造山带的冲断挤压应力通过塘古巴斯坳陷NEE向弧形断裂传递到塔中隆起，斜向作用于塔中隆起NNE向的基底软弱带之上，导致断裂上部地层被撕裂产生走滑分量，从而形成了NNE向的左旋走滑断裂系统。此外，由于南天山洋（特别是西南天山洋）俯冲消减所产生的向北西向南东的挤压应力近垂直向作用于走滑断裂上，导致NNE向走滑断裂发生压扭变形。

（3）晚志留世—中泥盆世，走滑断裂发生继承性活动和调整改造。一方面，来自塔里木板块南缘的挤压应力继续斜向作用于NNE向走滑断裂之上导致其继续发生走滑变形；另一方面，从晚志留世开始，南天山弧后盆地逐渐形成，塔里木板块北缘的构造环境由区域挤压转变为区域伸展，受南天山洋弧后裂谷作用产生的NW向伸展应力近垂向作用于走滑断裂上，导致整个NNE向走滑断裂发生张扭变形。

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