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东昆仑五龙沟金矿矿集区韧性剪切带构造变形特点研究

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提要:野外构造解析和显微构造分析表明,五龙沟地区经历了长期构造演化,具有多层次多期构造作用产物叠生特点。可分为早印支期(240 Ma左右)及其以前的韧性变形;晚印支—早燕山期的(235~197 Ma)的脆韧性变形;晚燕山期以来,尤其早−中喜马拉雅期(51~21 Ma)的脆性变形。晚印支期—早燕山期的脆−韧性变形,与造山隆升相伴,表现为先存变质核杂岩构造北东翼构造岩类的褶皱、断裂,奠定了五龙沟地区北西西向的构造主线,即形式上的数条北西西向韧剪带平行展布,从韧性变形、韧−脆性变形到脆性变形的构造运动依次为左行正滑→左行逆冲→右行正滑。

关 键 词:构造演化;脆韧性变形;构造运动;晚印支期—早燕山期;青海省
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A study of the deformation characteristics of the ductile shear zone in the Wulonggou gold ore concentration area, East Kunlun, Qinghai

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Abstract: Field structural analysis and microstructural analysis show that Wulonggou area has experienced a long−term structural evolution, characterized tectonically by multi− level and multi− storeyed products. Its can be broadly divided into the ductile deformation that occurred in early Triassic (240 Ma ±) and its previous period, late Indosinian − early Yanshanian (235−197 Ma) brittle− ductile deformation; brittle deformation that occurred after late Yanshanian period, especially in the early − middle Himalayan period (51−21 Ma). Late Triassic−Early Yanshanian brittle−ductile deformation was accompanied by orogenic uplift, and its performance was exhibited by the folding and faulting of the pre−existing metamorphic core on the northeast wing of the

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tectonites, which laid the foundation of the NWW-trending main tectonic line in the Wulonggou area, i.e., a number of formal NWW-trending ductile shear zones exhibit parallel distribution, with the tectonic activities developed in order of left-handed positive sliding- left-handed thrusting →right-handed positive sliding.

Key words: tectonic evolution; brittle-ductile deformation; activity order; late Indosinian-early Yanshanian; Qinghai Province

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1 引 言

剪切带是一种非常重要的控(成)矿构造,与剪切带有关的金矿床或"剪切带型金矿"在世界各地分布广泛,并往往形成大型、超大型金矿床,如太古宙绿岩地体中的脉状金矿、显生宙活动大陆边缘增生造山带中的造山型金矿[1-5]。国内外大量研究结果表明,含大型-超大型金矿床的剪切带往往经历了漫长复杂的构造演化历史,其中韧性-韧脆性转换、多期次构造叠加以及同构造岩浆活动等可能是控制含金剪切带成矿强度的重要因素。自20世纪80年代以来,已在东昆仑五龙沟地区剪切带内40余条构造破碎带上圈定了100多个金矿体,但其规模普遍较小,与剪切带的宏大规模相比极不相称。

因此,有必要对五龙沟剪切带的构造演化历史、变形变质序列进行研究,以准确评价其成矿潜力。笔者主要通过该区剪切带构造变形特点研究,希望对该区下一步找矿方向提供新思路,并对东昆仑的动力学背景研究提供有力支撑。

2 地质概况

五龙沟金矿矿集区位于东昆仑中段的北缘。处于昆中和昆北断裂夹持的构造岩浆岩带上。主构造线方向为北西-南东向。区内褶皱构造不明显,但断裂构造十分发育,呈现出多组断裂构造相互交切的格局。断裂依走向可分为北西、南北、北东、东西向4组,其中以北西向最为发育,是区内规模较大、形成较早、发育程度较高的一组脆性断裂,也是区内最主要的控矿断裂,多叠加于韧性剪切带之上,沿走向有分枝、复合、侧列及"S"型扭转现象。该组断裂分布具群集和等距规律,一般平面间距800~1000 m,在剪切带内侧及上盘多条成群产出,而远离剪切带则稀疏,单条断裂宽几米至数十米,长可达数千米。

昆中构造带发育有若干变质核杂岩构造。五龙沟地区就处于东北侧的金水口穹隆状变质核杂岩构造与西南侧的格尔木—五龙沟短轴背斜状变质核杂岩构造之间,主体属后者的东北翼[6-8]。受区域昆中和昆北深断裂强烈活动的影响,区内发育3条近于平行展布的韧性剪切带[9](图1)。自北东而南西依次为岩金沟剪切带、萤石沟—红旗沟剪切带、三道梁—苦水泉剪切带,一般延长在10 km以上,南东延展达昆中断裂带,北西段向西偏转有并入昆北断裂带的趋势,总长大于50 km,糜棱岩类构造岩出露宽度500~1000 m,产状20°~50°∠50°~80°。上述3条剪切带,分隔和控制了本区现今构造的北西向条块格局[10]。

3 韧性变形特征

韧性变形以形成糜棱岩为特征,利用糜棱岩中的碎斑系、云母鱼、S-C组构、书斜构造等显微构造,以及相伴的褶皱构造,可判断韧性变形阶段的变形序次[11,12]。

位于Ⅱ号剪切带的NE倾斜的萤石沟—红旗沟最北段(图2),韧性变形阶段普遍具有以左行为主的正滑剪切运动特征,见于长英质、黑云母花岗质、花岗闪长质等各类糜棱岩中。在垂直糜棱片理走向的切片中S-C组构(图3-a)、斜列的细长条长英质(图3-b)、眼球状长石碎斑晶纹(图3-c)、菱形长石碎斑(图3-d)、石英条带的钩状褶皱(图3-e)、δ型长石碎斑(图3-f)等均显示上盘向下、下盘向上的正滑剪切运动特征。

在平行糜棱岩片理的切片中书斜状排列的石英碎斑(图4-a、b)、S-C组构(图4-c、d)、显示在走向方向上左行剪切运动特征。δ型石英碎斑及书斜构造则指示右行剪切运动特征(图4-e、f)。综上显微构造分析,在韧性变形阶段本地区变形构造以左行正滑为主,局部出现右行正滑。

4 韧-脆性变形特征

脆-韧性阶段变形,以糜棱岩中劈理构造广泛

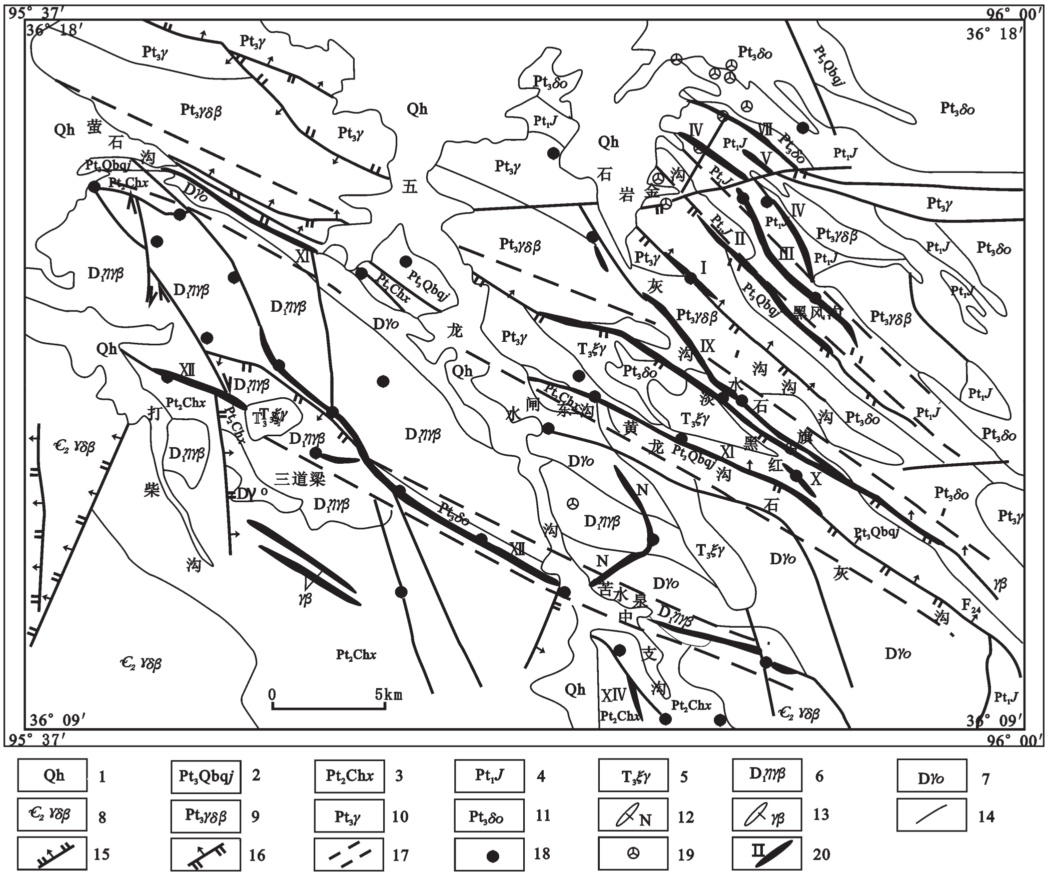

图1 五龙沟地区区域地质构造简图[9]

1—第四系冲洪积层；2—丘吉东沟组；3—长城系小庙组；4—金水口岩群；5—晚三叠世钾长花岗岩；6—早华力西期黑云母二长花岗岩；7—早华力西期蚀变斜长花岗岩；8—早加里东期黑云花岗闪长岩；9—新元古代黑云花岗闪长岩；10—新元古代含暗色包体花岗岩；11—新元古代石英闪长岩；12—基性岩脉；13—黑云母花岗岩脉；14—地质界线；15—实测及推测正断层；16—实测及推测逆断层；17—韧性剪切带；18—金矿床（点）；19—多金属矿床（点）；20—含金蚀变带及编号

Fig.1 Geological sketch map of Wulonggou area[9]

1−Quaternary diluvium; 2−Qiujigou Formation; 3−Xiaomiao Formation of Changcheng System; 4−Jinshuikou rock group; 5−Late Triassic feldspar granite; 6−Indo−Chinese biotite adamellite; 7−Indo−Chinese altered plagioclase granite; 8−Early Caledonian biotite granodiorite; 9− Late Proterozoic biotite granodiorite; 10−Late Proterozoic dark inclusion−bearing granite; 11−Late Proterozoic quartz diorite; 12−Basic vein; 13−Biotite granite vein; 14−Geological boundary; 15−Measured/inferred normal fault; 16−Measured/inferred reverse fault; 17−ductile shear zone; 18−Gold deposit (ore spot); 19−Polymetallic deposit (ore spot); 20−alteration zone and its serial number

发育为特征。利用劈理与主剪切带的几何关系及不同产状劈理之间的交切关系可判断剪切运动的序次和方向[12,13]。

位于红旗沟PD601沟脑的石英糜棱岩中（图5），早期正滑的缓倾劈理被晚期逆冲的陡倾劈理切过，且正滑同时伴有右行剪切，使糜棱岩片理褶皱形成倾竖褶皱。

类似现象在萤石沟—红旗沟剪切带的中段水闸东沟（图2）以及东南段淡水沟、红旗沟等地均能见及。在石灰沟剪切带（图6），沿剪切带追索各观察点可见2~3期劈理。那里指示逆冲的陡倾劈理将岩石切割成一系列陡倾构造透镜体，透镜体中仍保留有早期指示正滑的缓倾劈理，陡倾劈理及伴随的构造透镜体又被后期的缓倾劈理切过，表明剪切带经历了正滑→逆冲→正滑的运动序次。在岩金沟剪切带（图7）也有3期劈理，早期正滑缓倾劈理，中期逆冲陡倾劈理，在各剖面上均能见及，晚期正滑缓倾劈理见于剪切带WN段（图7剖面Ⅰ）。在SW倾斜的三道梁—苦水泉剪切带（图8）利用劈理及褶皱判定的运动序次与上述NE倾斜的剪切带不同，普遍为早期逆冲，晚期正滑。在LWG08点（图8）糜棱面理产状196°∠64°，198°∠68°，早期劈理产状0°

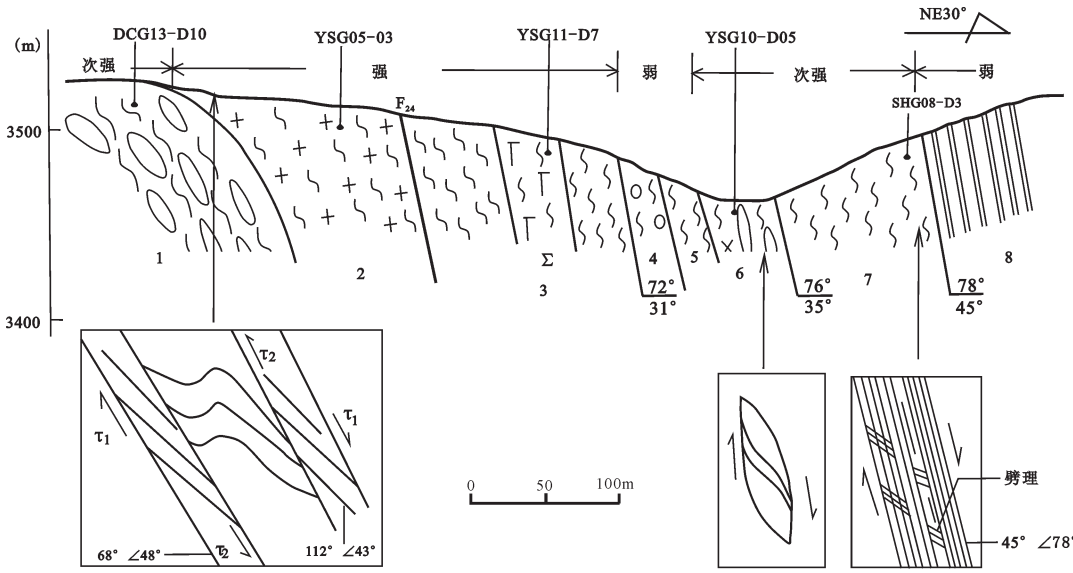

图2萤石沟(YSG) —红旗沟(HLG)剪切带构造剖面图

1—片理化花岗岩、辉石岩混杂的构造透镜体化带;2—花岗质片糜岩带;3—凝灰质片糜岩、片理化橄榄辉石岩(∑);4—片理化变质砾岩;5—片岩夹大理岩;6—含构造透镜体的花岗闪长质片糜岩;7—劈理化凝灰质片岩;8—千枚岩、板岩

Fig.2 Tectonic profile of Yingshigou(YSG)−Hongqigou (HLG) ductile shear zone

1−Lens zone of schistose granite and pyroxenite; 2−granitic schistose mylonite zone; 3−Tuffaceous schistose mylonite zone, schistose olivine−pyroxenite (∑); 4−Schistose metamorphic conglomerate; 5−schist intercalated with marble; 6−Mesozoic granodioritic lens−bearing schistose mylonite; 7−Cleavage tuffaceous schist; 8−Phyllite, slate

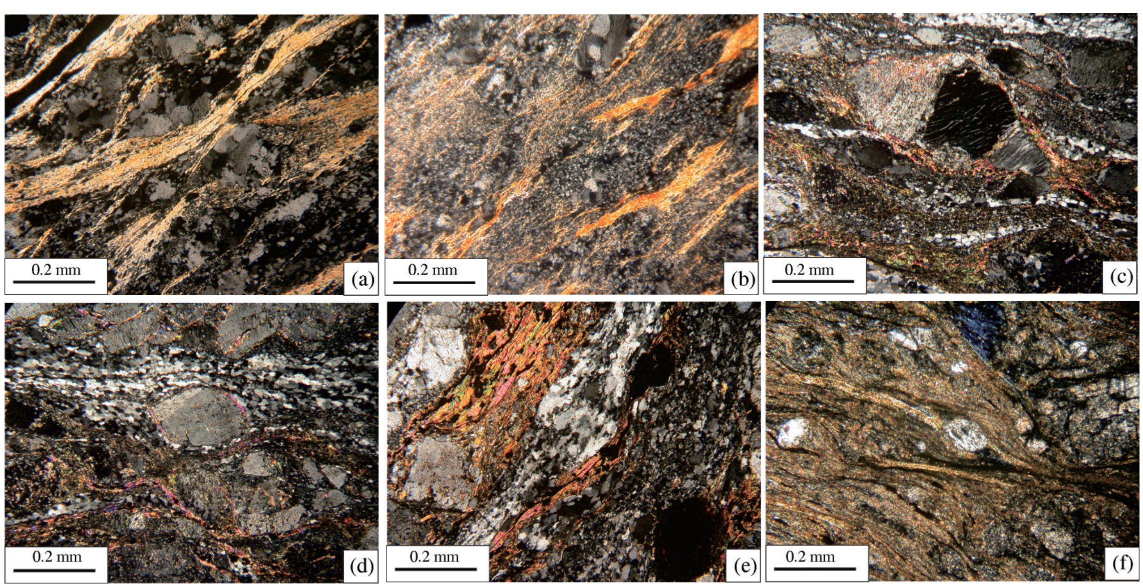

图3 萤石沟—红旗沟剪切带垂直片理切片(正交偏光)

a和b萤石沟YSG10−D5,a—S−C组构;b—斜列的细长条石英质碎斑;c和d萤石沟YSG10−D5,c—眼球状长石碎斑晶纹条带,d—菱形长石碎斑;e—萤石沟YSG11−D7,石英条带的钩状褶皱;f—石灰沟SHG008−D3,δ型长石碎斑

Fig.3 Microphotographs of Yingshigou−Hongqigou vertical schistosity zone (crossed nicols)

a and b−Yingshigou YSG10−D5, a−S−C fabric; b−Elongated echelon quartz porphyroclast; c and d−Yingshigou YSG10−D5, c−Augen feldspar phenocrysts broken stripe pattern, d−Diamond feldspar porphyroclast; e−Yingshigou YSG11−D7, hook fold of quartz bands; f −Shihuigou SHG008−D3 δ feldspar phenocrystal

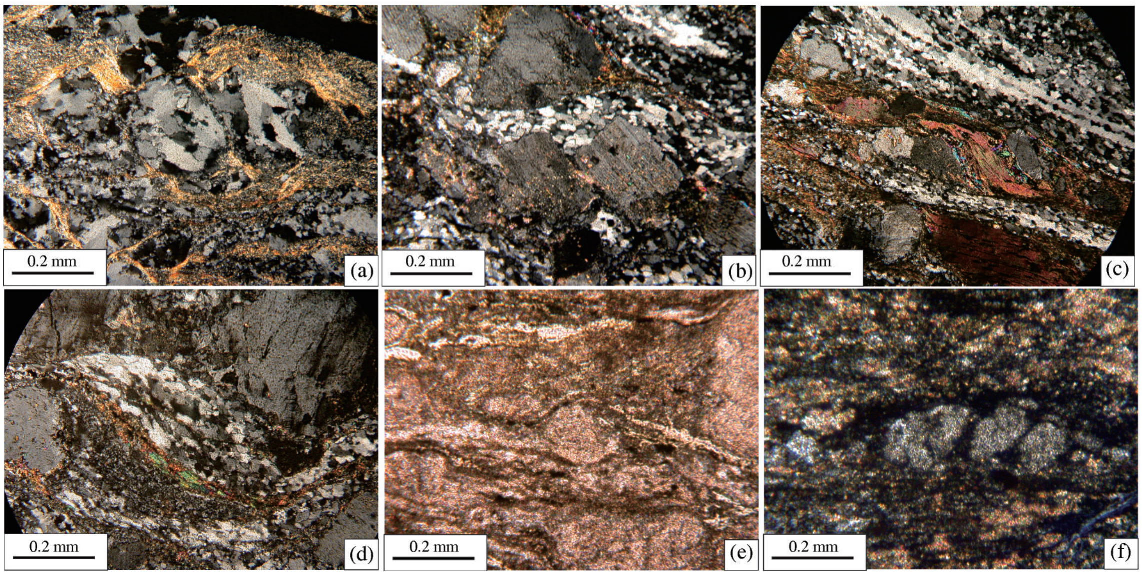

图4萤石沟—红旗沟剪切带平行片理切片(正交偏光)

a~b左旋石英碎斑书斜构造, a—YSG05−D3(2);b—YSG10−D5(2);c—YSG10−D5(2)左旋之S−C组构和云母鲕;d—YSG11−D7(2),石英、云母条带显示的左旋S−C组构;e—SHG008−D3(2),单偏光,右旋的δ型石英碎斑系;f—SHG008−D3(2),右旋的石英碎斑书斜构造

Fig. 4 Microphotographs of Yingshigou−Hongqigou parallel schistosity (crossed nicols)

a−b: Structure of Left−handed quartz porphyroclast, a−YSG05−D3(2); b−YSG10−D5(2); c−YSG10−D5(2) left−handed with S−C fabric and mica oolite; d YSG11−D7(2), Left−handed S−C fabric with quartz and mica; e−SHG008−D3(2), plainlight, right lateral δ feldspar phenocrystal; f−SHG008−D3(2), right lateral quartz porphyroclast

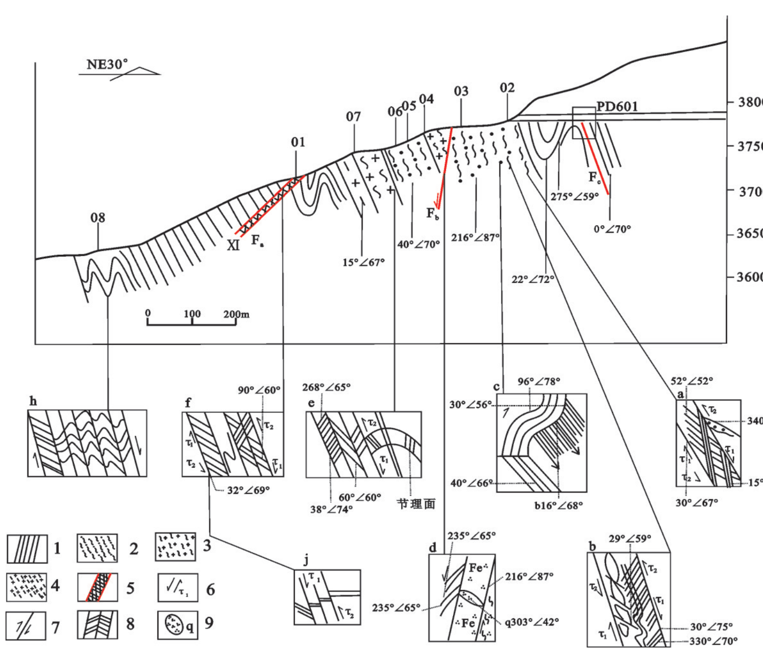

图5 红旗沟沟脑构造剖面图

1—凝灰质片岩;2—石英糜棱岩;3—花岗质糜棱岩;4—花岗质碎裂岩;5—矿体;6—剪切方向及序次;7—断层;8—劈理;9—石英脉

Fig. 5 Tectonic profile of Hongqigou pithead

1−Tuffaceous schist; 2−Quartz mylonite; 3−Granitic mylonite; 4−Granitic cataclasite; 5−Orebody; 6−Shear direction and order; 7−Fault; 8−Cleavage; 9−Quartz vein

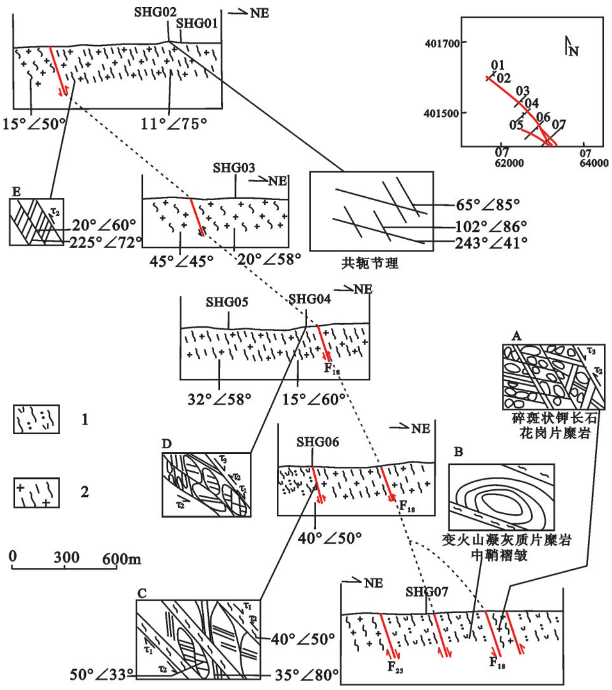

图6石灰沟01~07点联合剖面图

1—凝灰质片糜岩;2—花岗质片麻岩

Fig. 6 Combined profile of Shihuigou 01−07 points

1−Tuffaceous schoistose mylonite; 2−Granitic gneiss

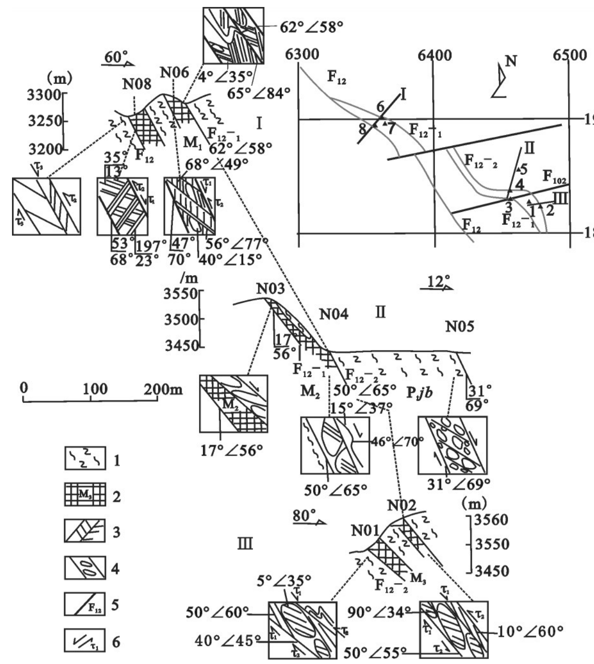

图7 岩金沟剪切带联合构造剖面图

1—黑云斜长片麻岩;2—金矿体及编号;3—劈理;4—构造透镜体;5—断层及编号;6—剪切方向与序次

Fig. 7 Combined profile of Yanjingou shear zone

1−Biotite−bearing plagioclase gneiss; 2−Gold orebody and its serial number; 3−Cleavage; 4−Tectonic lens; 5−Fault and its serial number; 6−Shear direction and order

∠70°,指示逆冲,它被产状为137°∠39°的指示正滑的缓倾劈理切过。

综上所述,若将SW倾斜的三道梁—苦水泉剪切带恢复为原始向NE倾斜,则整个五龙沟地区的剪切带,在脆−韧性阶段至少统一经历了两期变形,早期上盘由SW向NE伸展正滑,它实为韧性阶段正滑剪切的延续;晚期上盘由NE向SW逆冲,伴有主剪切面褶皱,三道梁—苦水泉剪切带由NE倾斜转变为SW倾斜,岩金沟剪切带逆推至萤石沟—红旗沟剪切带之上,相应形成由主剪切面弯曲构成的猴头山复背斜形构造及萤石沟—红旗沟同斜倒转向斜构造。部分地区在逆冲之后出现的正滑剪切,已是脆性变形阶段形成的。

5 脆性变形特征

在脆性变形阶段,各剪切带普遍转变为脆性断层,除在沿先存脆韧性剪切面发育的断层中,出现断层角砾岩、构造透镜体、断层泥及邻断裂劈理、拖拽褶皱、节理等构造外,在剪切带内及旁侧形成一系列低序次的脆韧性断层。研究这些构造现象,可判别主剪切带脆性变形的过程[11,14]。

在红旗沟沟脑的构造剖面中(图5~9),剪切带中至少发育了Fa、Fb、Fc、Fd等4条脆性断层,它们的运动序次有助于判别主剪切带脆性变形阶段的变形过程。

从图5看到,观察点02~07发育了由石英糜棱岩、花岗质糜棱岩构成的糜棱岩带,厚约200 m,代表韧性、脆−韧性主剪切带。糜棱岩面理产状0°~40°∠67°~75°,平均为25°∠71°。Fa位于主剪切带西南侧,X−1矿体沿Fa分布。Fa产状246°∠44°(顶板)、236°∠36°(底板),略显向上张口状,且下盘断面起伏不平,上盘变凝灰质片岩片理的拖拽褶皱,显示为正断层。在顶板围岩中,早期指示正滑的近水平的构造透镜体,被指示逆冲的陡倾劈理(250°∠70°)切过,伴有陡倾的构造透镜体及反S型节理,陡倾劈理又被指示正滑的260°∠21°缓倾劈理切割,表明脆性断层Fa经历了正滑到逆冲到正滑的运动序次。

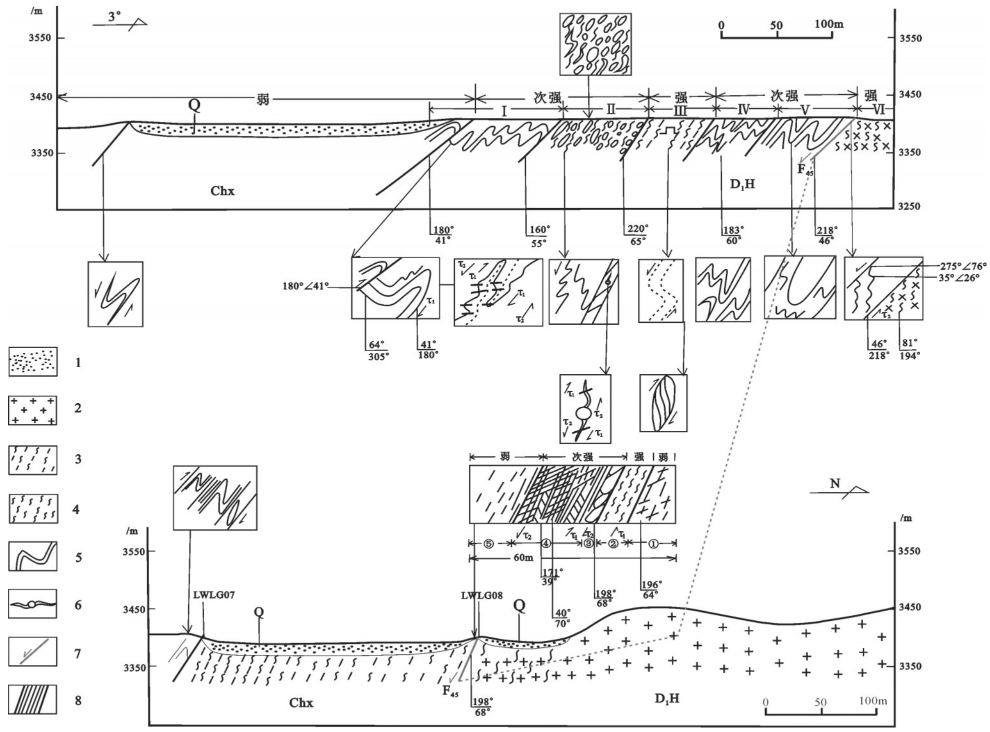

图8 五龙沟中游西岸三道梁—苦水泉剪切带剖面图

1—第四系；2—猴头山花岗岩(D_1H)；3—小庙群（chx）斜长片麻岩；4—糜棱岩；5—褶皱；6—碎斑；7—断裂；8—劈理；上图的构造分带：Ⅰ—早期逆冲，晚期正滑形成的小型褶皱带；Ⅱ—构造透镜体带；Ⅲ-强变形带与弱变形带交互构成的糜棱岩带；Ⅳ—强变形的揉皱带；Ⅴ—同斜倒转褶皱带；Ⅵ—糜棱岩化花岗岩；Ⅶ—猴头山花岗岩；下图附图为露头尺度上的构造分带：①—碎裂岩带；②—片糜岩带厚约10 cm，产状196°∠64°；③—构造透镜体带厚3-5 cm，产状198°∠68°，其内171°∠39°的劈理发育，指示正滑剪切；④—密集劈理化带厚约20 cm，有三组辟理，主辟理产状198°∠68°，劈夹块中保留有北陡倾之逆冲辟理，并被向南缓倾之正滑劈理切过，说明早期(τ_1)逆冲，晚期(τ_2)正滑；⑤—碎裂岩带，为弱变形带，劈理较不发育

Fig. 8 Geological section of Sandaoliang-Kushuiguan shear zone of Wulonggou middle valley

1-Quaternary; 2-Houtoushan granite (D_1H); 3-Xiaomiao Group（chx）plagioclase gneiss; 4-Mylonite; 5-Fold; 6-Phenocrystal; 7-Fracture; 8-Cleavage; tectonic zoning of the upper diagram: Ⅰ-early thrust, miniature fold belt of late normal slip; Ⅱ-Tectonic lens; Ⅲ-Mylonite zone formed by strong deformation and weak deformation zone; Ⅳ- Rumple zone of strong deformation; Ⅴ-Congruous inversion fold belt; Ⅵ-Mylonization granite; Ⅶ-Houtoushan granite; cleavage; tectonic zoning of the lower diagram: ①-Cataclastic rock belt; ②-Schistose mylonite, 10cm thick, attitude 196°∠64°; ③-Tectonic lens, 3-5 cm thick, attitude 198°∠68°, cleavage (attitude 171°∠39°) well developed, indicating normal slip shear; ④-Dense cleavage zone 20cm thick, three cleavages well developed. Attitude of main cleavage 198°∠68°, indicating early(τ_1) thrust and late(τ_2) normal slip; ⑤-Cataclastic rock belt, weak deformation zone, and poorly-developed cleavage

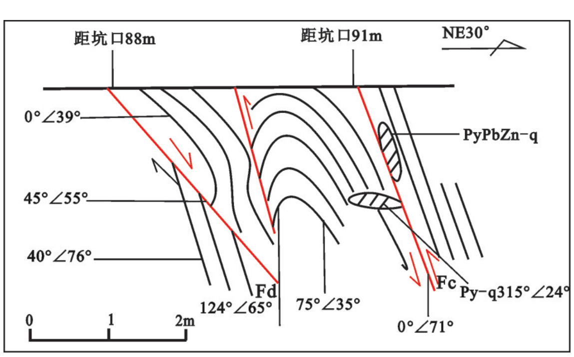

图9 红旗沟沟脑坑内Fc、Fd构造剖面图

Fig.9 Geologic Tectonic Drawing of Fc and Fd in tunnel internal PD601

Fb位于糜棱岩带中，产状216°∠87°，邻断裂劈理（235°∠65°）和充填有褐铁矿化石英脉的张节理（303°∠42°），指示为正滑断层。此外在06点的石英糜棱岩中节理发育，强烈变形使节理面弯曲，形成由共轭节理面构成的逆冲背形褶曲，且伴有扇状劈理，显示剪切带在脆性变形阶段发生过强烈的逆冲剪切运 Fc、Fd位于糜棱岩带上盘的PD601坑内（图9）。围岩为变凝灰质片岩，片理产状0°∠71°。Fd位于距坑口88 m处，产状45°∠55°，邻断裂的片理褶皱指示为正滑断层，表明主剪切带右行正滑运动。Fc位于距坑口91 m处，沿凝灰质片岩片理发育，下盘片理的褶皱及充填黄铁矿石英脉的张

表1 五龙沟金矿矿集区构造变形序次

Table 1 Tectonic deformation order of Wulonggou gold mine Ore Concentration Area

<table>
<tr><td>变形阶段</td><td>韧性</td><td colspan="4">韧-脆性</td><td colspan="5">脆性</td></tr>
<tr><td>深度</td><td>–25.5 ~ –10 km</td><td colspan="4">–0 ~ –2 km</td><td colspan="5">–2 ~ +4 km</td></tr>
<tr><td>剪切方向</td><td colspan="2">左行正滑为主
局部右行正滑</td><td colspan="2">左行逆冲</td><td colspan="2">右行正滑</td><td colspan="2">左行逆冲</td><td colspan="2">右行正滑</td></tr>
<tr><td>力学方向</td><td colspan="2">扭张</td><td>扭压</td><td colspan="2">张扭</td><td colspan="2">压扭</td><td colspan="2">张扭</td><td></td></tr>
<tr><td>构造事件</td><td colspan="2">昆南洋壳俯冲，昆中陆缘弧向南推覆，后不热隆扩展。同构造花岗岩侵入，变质核杂岩形成</td><td colspan="5">陆内俯冲造山，昆北，昆中，昆南断裂左行走滑挤压，剪切带褶皱变形</td><td colspan="3">青藏高原强烈隆升，昆仑山带向北推覆，柴达木南缘早第三纪前陆盆地形成</td></tr>
</table>

节理(产状315°∠24°)指示Fc为逆冲断层。此逆冲褶皱逆推至Fd上盘正滑褶皱之上,表明主剪切带在右行正滑之后发生逆冲剪切运动。沿Fc断层面上分布的黄铁矿铅锌石英脉,石英的ESR年龄为(57.1±5.7)Ma,说明主剪切带在逆冲之后于新生代发生正滑运动。

综合上述Fa、Fb、Fc、Fd脆性断层的研究,五龙沟地区走向NWW的主剪切带,在脆性变形阶段的变形序次为:右行正滑剪切→左行逆冲剪切→右行正滑剪切。

6 构造变形基本序列

通过前面对韧性、韧-脆性、脆性变形特征的研究和分析,结合野外实际地质情况表明,该地区的断层发生过不止一期的变形活动,通过该地区的节理发育情况可以有其切割关系进行分期配套,从而判断其变形期次[15]。

本地区的脆性变形大致经历了4期以上的变形,主要的变形发生于一、二期,发育了(偏)北西向、(偏)北北西向和近南北向等3组断裂。三、四期主要表现为走滑和逆冲,且强度相对较小。其活动顺序右行正滑→左行逆冲→右行正滑。

7 结 论

古生代—中三叠世,昆中和昆南—阿尼玛卿洋壳相继向北俯冲。昆中陆源岩浆弧热隆扩展,变质核杂岩及其伸展剥离韧性剪切带形成;晚三叠世—早白垩世,陆内走滑俯冲造山作用,导致剪切带褶皱变形的变质核杂岩构造形成,伴有同构造岩浆活动,发生早期韧-脆性阶段成矿;晚白垩世—新近纪,青藏高原隆升,昆仑山向北走滑推覆,推覆体中后部的五龙沟地区隆升扩展,大规模脆性变形,混源的含矿热液广泛活动,并聚集于有利的容矿构造空间,最终导致金矿质的巨量聚集。五龙沟地区在海西—印支期内至少发生过两期韧性变形事件:大致可分为早印支期(240 Ma左右)及其以前的韧性变形;晚印支—早燕山期的(235 ~197 Ma)的脆韧性变形;晚燕山期以来,尤其早—中喜马拉雅期的脆性变形,晚燕山期以来(51~21 Ma)的脆性变形,各层次构造变形序次如表1。

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