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低序次韧性断裂的负反转构造研究

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内容提要 赣湘地区的变质核杂岩和变质穹窿构造中, 晚期脆性断裂与早期低序次韧性构造间存在着明显的相关联系。这是由于韧性断裂中的面理(S_2), 经劈理、节理多次转化, 由压性构造转化为张性构造并形成伸展型的脆性断裂。其演化机制在宏观上是碰撞造山形变后期的引张作用; 微观上是岩石物体加工硬化的方向性等缘故。并综合分析了在荷载、边界变化的条件下, 应力、应变在宏—微观上的重新分配(partitioning), 导致低序次韧性构造向脆性断裂负反转的必然趋势。这方面的研究, 不论在资源或是环境地质调查中均有实践意义。

关键词 负反转构造 低序次构造 引张作用 加工硬化 赣湘地区

上世纪80年代兴起的反转构造研究(Cooper et al., 1989), 同碰撞造山带的构造演化(Sun et al., 2001), 沉积盆地的构造演化(朱文斌等, 2003), 尤其同伸展变质核杂岩、变质穹窿和蚀顶构造的研究密切相关(Faure et al., 1996; Roger et al., 2000; Roden-Tice et al., 2000)。这诸多构造现象尽管在动力来源、发育过程上有所差异, 然而在运动特征、

力学成因上却均有关联, 并会屡屡观察到, 由压性转为张性的负反转构造。然而国内外研究者对其反向运动和发育过程的认识, 常限于同序次构造(Cooper et al., 1989)。90年代后期, 在赣湘地区, 中、法双方合作考察变质核杂岩和变质穹窿构造时, 发现晚期脆性断裂与早期低序次韧性构造存在明显的相关性, 多数是不同序次构造的转化。

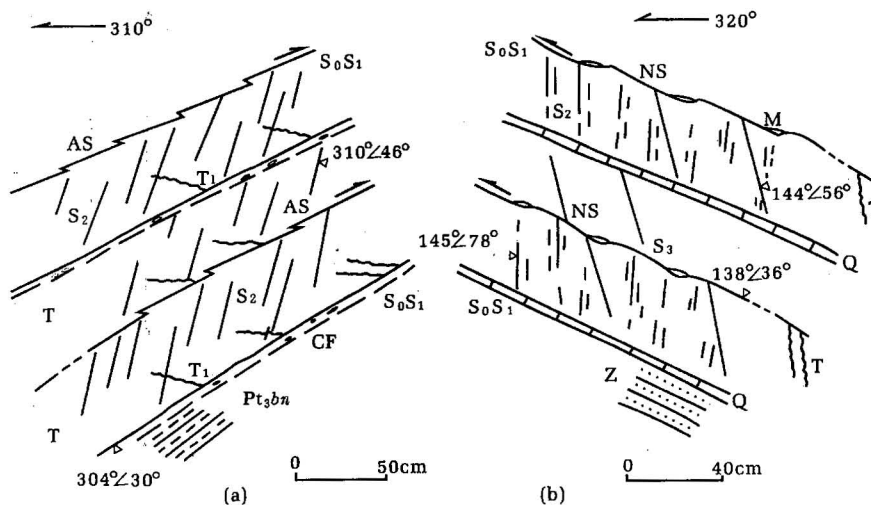


图1 湘西古丈城西新元古界板溪群(Pt_3bn)地层(a)和赣北庐山如琴湖西岸震旦系(Z)地层(b)中发育的低序次面理构造剖面图

Fig. 1 The structural cross section showing subordinate foliations in the Neoproterozoic Banxi Group to the west of Guzhang city, western Hunan(a) and in the Sinian strata to the western bank of Ruqing Lake in Lushan, northern Jiangxi(b)

AS—反阶步; NS—正阶步; M—应力矿物; Q—石英脉; CF—碎裂流动; T、 T_1 —张性裂隙

AS—Anti-step; NS—normal step; M—stress mineral; Q—quartz vine; CF—cataclastic flow; T, T_1 —tensile crack

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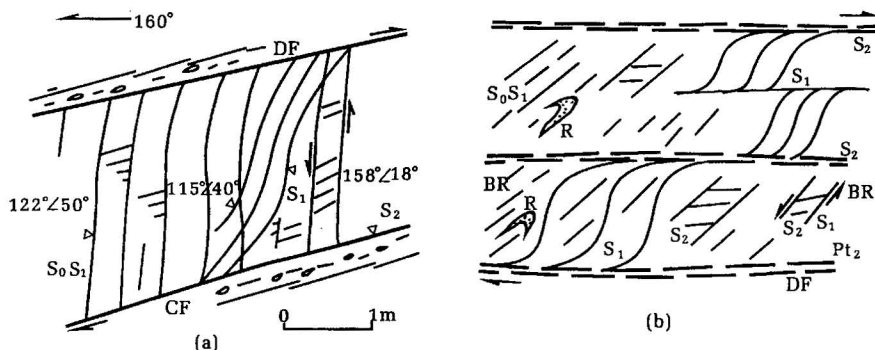


图2 江西上高界埠上湾震旦系(Z)地层(a)和中元古界双桥山群(\$Pt_2\$)、冷家溪群(\$Pt_2l\$)地层(b)中发育的面理拖曳(其他说明同图1)

Fig. 2 Drag foliations in the Bushangwan Sinian strata of Shanggaojie, Jiangxi(a) and in the Mesoproterozoic Shuanqiaoshan Group and Lengjiaxi Groups(b)

(symbols are the same as in Fig. 1)

BR—产状倒转; DF—韧滑流动; R—钩状褶皱

BR—Attitude reverse; DF—ductile slip flow; R—hooked fold

1 低序次韧性构造

序次(order)概念为中国地质学家较早倡导和应用(李四光, 1962), 认为应力作用方式(\$y\$)是边界条件(\$x\$)的函数, 即 \$y=f(x)\$。为此在运动样式不变时, 可产生初次、再次构造。近几年有的学者提出低序次(subordinate)构造(Lin et al., 2001), 与上述所指的含义相仿。

在赣湘变质岩地区, 常见的与晚期脆性断裂有关的低序次韧性构造主要由面理 \$S_2\$ (\$S_3\$ 次之), 再经劈理、节理多次转化而成, 通常有两种情况:

(1) 面理呈平面状: 不论在浅变质的震旦系或深变质的元古宙地层中, 都能观察测量到面理产状要素, 图1中(a)、(b)两个地点的面理 \$S_2\$ 和 \$S_3\$ 都呈平面状。图1a中, \$S_0\$ 为原始层理, \$S_1\$ 为顺层韧性滑移产生的面理, 产状与 \$S_0\$ 一致, 顺层韧性滑移同时产生切层的密集 \$S_2\$ 面理, 与 \$S_1\$ 交角 \$50^\circ \sim 55^\circ\$。晚期的顺层滑动产生韧性—脆性反阶步(AS), 并派生张性裂隙(\$T_1\$), 且沿平行层面的小型滑脱面出现碎裂流动(CF)(cataclastic flow), 实际上是一种非均匀性流动(heterogeneous flow)(Mandal et al., 2001)。图1b中, \$S_0\$、\$S_1\$、\$S_2\$ 的地质意义同图1a, 晚期的顺层滑动产生正阶步(NS), 派生的具有韧性—脆性的剪切面理 \$S_3\$, 同 \$S_1\$ 的交角 \$55^\circ \sim 60^\circ\$, 其小型滑脱面为石英脉充填。图1(a)、(b)两地所见现象, 沿山脚一

线均很发育, 并近临空面一侧, 面理(\$S_2\$、\$S_3\$)明显转化成劈理、张裂隙(\$T\$), 其上屡见下滑擦动痕迹和泥质填充(图1a、b)。

(2) 面理呈拖曳状: 赣湘地区中元古代地层, 由于受大规模逆冲推覆和多期构造变动影响, 产生了诸如倒转、平卧的构造产状, 同斜、钩状的叠加褶皱(Lin et al., 2000)。其面理常呈拖曳状, 见图2a、2b, 其中图2a是实测, 图2b则是常见的代表模式, 这在元古宙地层中俯拾皆是。图2中 \$S_0\$ 为原始层理, \$S_1\$ 为顺层韧性滑移产生的面理, 产状与 \$S_0\$ 一致, 且与钩状褶曲 \$R\$ 的轴面平行。\$S_2\$ 为后期剪切形成的面理, 并常被误当成地层层面。后期剪切作用造成早期 \$S_1\$ 面理变形呈拖曳状, 变化较烈者呈拖曳构造, 局部见残斑系, 示运动方向(Faure et al., 2000)。且后期脆性裂隙多与早期韧性 \$S_1\$ 面理重叠, 并可见转化成张性构造的明显迹象, 其动向可借助擦痕、擦脊来确定。

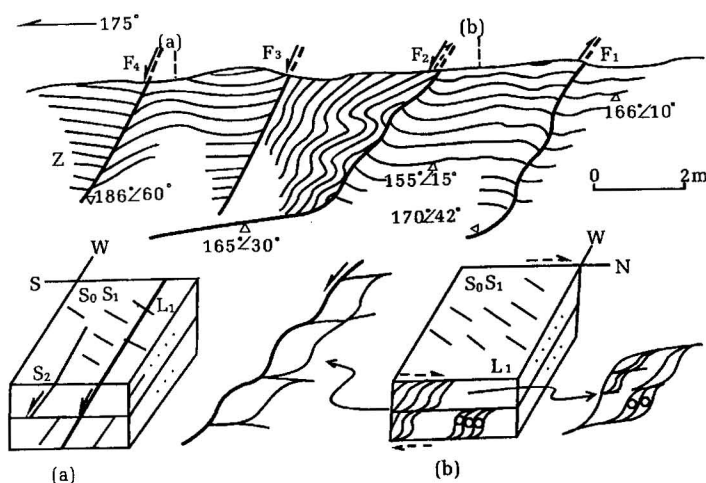


图3 江西安福洋溪钱山震旦系(Z)地层中平行 \$S_2\$ 面理发育的相关断层(下方图(a)、(b)为主图中(a)、(b)处的详图, 虚线箭头示前期动向, 其他说明同前)

Fig. 3 Related faults in the Qianshan Sinian strata of Yangxi, Anfu, Jiangxi, which parallel foliation \$S_2\$ (small fig. s (a) and (b) at the bottom showing details of (a) and (b) in the main section, dashed line arrow indicates early movement direction, the other symbols are the same as before

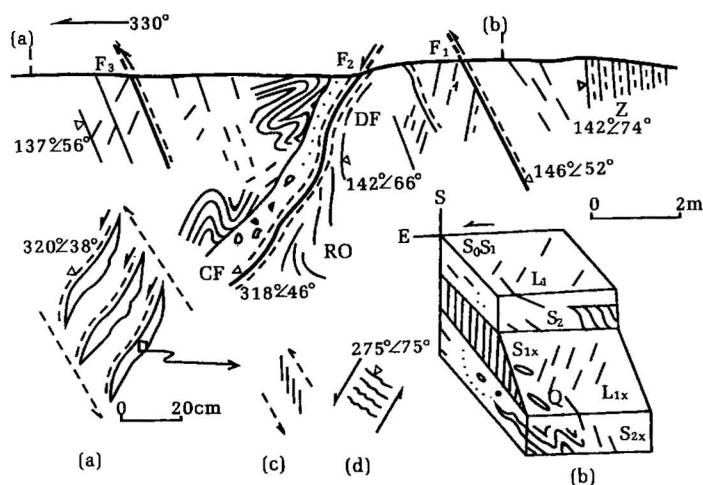


图4 江西庐山含鄱口一大山间震旦系地层中平行 S_{2x} 面理发育的相关断层[下方图(a)、(b)为主图中(a)、(b)处的详图;下方图(c)、(d)为图4(a)中所示方框处的详图,其他说明同前]

Fig. 4 Related faults in the Hanfankou—Dashanjian Sinian strata of Lushan, Jiangxi, which parallel foliation S_{2x} [small fig.s (a) and (b) at the bottom showing details of (a) and (b) in the section, small fig.s (c) and (d) showing details of block diagram in the Fig. 4 (a), the other symbols are the same as before]

RO—旋扭构造;Q—石英杆构造

RO—Rotation and shearing structure; Q—quartz rodding structure

2 负反转构造发育过程

研究区内早期面理有两种情况,一种平行于层理 S_0 ,称之为 S_1 ,与之对应的晚期面理是 S_2 ;一种斜交层理 S_0 ,称之为 S_{1x} ,与之对应的晚期面理是 S_{2x} 。

(1) 平行 S_2 面理发育的相关断裂(早期 S_1 平行 S_0):图3表现为 S_1 平行 S_0 ,构造现象相对简单直观,平稳和谐。早期断层由沿 S_2 面逆冲推覆,后期沿 S_2 面(图3a, F_3 和 F_4),或是由 S_2 面发育起来的透镜体(残斑系集合体)的边缘引张下滑(图3a, b, F_2)。

(2) 平行 S_{2x} 面理发育的相关断裂(早期 S_1 不平行 S_0):图4中,面理 S_1 与层理 S_0 明显不一致(图4 a, b),面理 S_1 是由切层滑动形成的,与层理 S_0 交角约 $5^\circ \sim 8^\circ$,且 S_1 面间往往本身亦被切割,交角可增大至 $8^\circ \sim 12^\circ$,故称 S_{1x} 面(图4b),其构造现象相对复杂多变。图4中在同一断层会见到拖曳、反拖曳褶皱;伴生和派生裂隙构造(旋扭构造RO);碎裂和韧滑流变(CF、DF)。可从互不协调的现象中判别断层演化阶段、动向变化(图4, F_2)。而早期呈斜列韧性变形的石英杆状构造(图4a),后

期沿平行晚期面理 S_{2x} 方向引张下滑,且在石英杆上可发现剪切、拉张两期微细裂隙(图4c、d)。若是露头良好的话,在上述构造附近可发现台阶状断层,断层转折和传播相关褶皱(图5)(Suppe, 1990)。重要的是 S_{2x} 与主断面产状一致,由压转张同步进行。

3 低序次构造向负反转断裂演变的机制

依照当代科学的观念,研究地质构造演变机制主要应从宏观和微观两个方面进行讨论(Meakin, 1998):

(1) 宏观方面——碰撞造山形变的后期引张作用:经观察研究,赣湘地区九岭山和雪峰山等作为成熟的山链,其碰撞造山作用可划分为三个演化阶段,即挤压逆冲隆升—走滑逃逸流变—引张伸展反转阶段(舒良树等,1995)。早期挤压阶段,由于逆冲作用加剧,伴随顺层和切层滑动产生的面理,也随地层一并倒转。晚期引张阶段,由于伸展作用发育(包括倾滑滑脱和重力滑脱),不仅同序次的断裂而且低序次的裂隙面理均向负反转构造演变。在宏观区域上,这同碰撞造山后期浅层岩片垂向运动活跃的大背景是分不开的(Kuda et al., 2001)。同位素测年显示,该区负反转构造作用发生在晚印支期至早燕山期,已测年龄段在 $233.5 \pm 5.0 \sim 225.6 \pm 2.9$ Ma 和 $131.7 \pm 1.7 \sim 122.9 \pm 2.4$ Ma(舒良树等,1995; Sun et al., 2001)。

(2) 微观方面——岩石物体加工硬化的方向性:岩石物体的加工硬化亦称工作硬化,通常理论

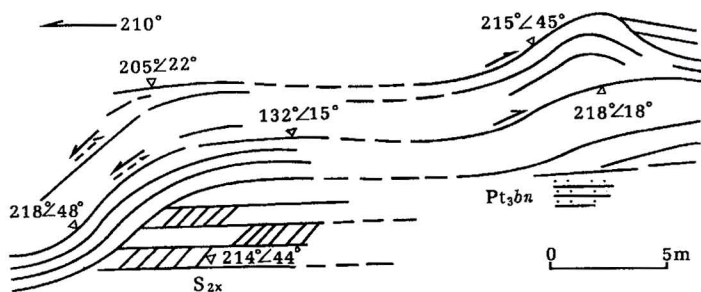


图5 湘西古丈县城西新元古界板溪群(Pt_3bn)地层中台阶状断层(S_{2x} 平行断层 F_1 ,图例说明同前)

Fig. 5 Fault bent fold in the Neoproterozoic Banxi Group to the west of Guzhang county, western Hunan (S_{2x} parallels fault F_1 , the other symbols are the same as before)

上只强调继续变形困难的一面,忽视了具有明显方向性的一面。即表现在岩石物体压缩变形后再行压缩,由于材料的比例极限和屈服极限都提高了,故继续变形就比较困难。但如果进行反向拉伸形变,却反而变得容易了。这种现象通称为鲍辛格(J. Baushinger)屈服效应(孙岩等,1998;Wang et al., 2001)。若把这种微观效应运用到岩体变形的分析上,表明比起压缩正向力小得多的引张反向力,就可产生压转张、先压后张的变形。区内的低序次面理构造,具有压性或压扭性的性质, S_2 面理尤为清楚,其转化为负反转构造,鲍辛格效应的制约作用是普遍的。

总而言之,不论宏观或微观方面,低序次韧性构造演变成负反转构造,都是应力作用方式的改变所致。低序次构造发育过程中荷载增减、边界繁简等各种变化,必导致应力、应变的重新分配作用(partitioning)(Hippertt et al., 2001),处于山体的临空面尤为明显,加上重力的作用,向负反转构造演化则势所必然。

上述这些负反转脆性断裂均是中生代成矿断裂和新生代灾害断裂中的优势面(preferred plane)构造(罗国煜等,2000),对其研究不论在资源或环境地质的调查中,均有实践意义。

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A Study on Negative Inverse Structure of the Subordinate Ductile Fault

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Abstract

In the metamorphic core complex (MCC) and the metamorphic arch, Jiangxi and Hunan area, there is an obvious correlation between the late brittle fault and the early subordinate ductile structure. It is considered that extensional type brittle faults could be generated through multiple transformations from ductile foliations (S_2) to cleavages and joints, and mainly owing to the tectonic deformation from compressive to tensile. The evolution mechanism is due to a lot of causes not only a tensile action of the late period in the collision orogenic deformation in the macroscopic scale, but also a direction character of the process hardening of the rock body in the microscopic scale. A new partitioning of the stress and strain in a condition of load and boundary has been synthetically analysed in the macroscopic and microscopic scales, thus it will be inevitable trend that the subordinate ductile structure can transform into the brittle fault in the MCC, metamorphic arch and collision orogenic deformation. In this research as mentioned above, there is the important significance of practice investigation both the mineral resources and the environment geology.

Key words: negative inverse structure; subordinate structure; tensile action; process hardening; Jiangxi—Hunan area
