

赞皇杂岩官都岩群时代与物源

——来自黑云变粒岩与石英岩碎屑锆石 U-Pb-Hf 同位素与 稀土元素组成的约束

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摘要: 官都岩群是华北克拉通中部造山带赞皇杂岩中重要的变质火山-沉积岩系, 经历了高绿片岩相-高角闪岩相变质, 准确限定其沉积时代与物质来源对探究中部造山带新太古代-古元古代构造演化过程具有重要意义。利用 LA-MC-ICP-MS (多接收激光剥蚀电感耦合等离子质谱仪) 与 TIMA (矿物自动分析系统) 对官都岩群中黑云变粒岩与石英岩进行了锆石矿物包体、U-Pb-Hf 同位素与稀土元素原位分析。根据碎屑锆石内部矿物包体组成、阴极发光图像特征与 U-Pb 年龄结果, 认为黑云变粒岩与石英岩中碎屑锆石中最年轻一组的 $^{207}\text{Pb}/^{206}\text{Pb}$ 谐和年龄分别为 2 544 Ma 或 2 536 Ma, 大致限定了其原岩的最老沉积时代, 结合区内黄岔花岗岩岩体侵入官都岩群的野外地质关系, 推测官都岩群沉积时代为新太古代末期, 并非古元古代。官都岩群黑云变粒岩与石英岩碎屑锆石年龄图谱十分相似, 最主要的峰值年龄为 2 512 Ma, 结合碎屑锆石内部矿物包体与结构特征, 认为官都岩群主要物源为新太古代晚期中酸性岩浆岩。两阶段锆石 Hf 模式年龄揭示 2 850 ~ 2 700 Ma 为赞皇杂岩最强烈的地壳生长阶段。综合本文与中部造山带已发表的数据, 认为官都岩群黑云变粒岩与石英岩中变质锆石记录了 ~2 500 Ma 的变质年龄, 表明华北克拉通中部造山带普遍遭受了 ~2 500 Ma 变质作用, 该期变质作用可能与新太古代晚期华北克拉通初步克拉通化有关。

关键词: 赞皇杂岩; 官都岩群; 变粒岩; 石英岩; 碎屑锆石

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Depositional age and provenance of the Guandu Group in the Zanhuan Complex, North China Craton: Constraints from detrital zircon U-Pb-Hf isotopic and rare earth element compositions in the biotite leptynite and quartzite

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Abstract: The Guandu Group, which has undergone high greenschist to high amphibolite facies metamorphism, is an important meta-volcanic and meta-sedimentary rock sequence in the Zanhuan Complex of the Trans-North China Orogen, North China Craton. Depositional age and provenance of the Guandu Group are vital for understanding the

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Neoproterozoic tectonic evolution of the Trans-North China Orogen. In this study, LA-MC-ICP-MS (laser ablation multi-collector inductively coupled plasma mass spectrometry) and TIMA (tescan integrated mineral analyser) were used to analyze mineral inclusions, U-Pb-Hf isotope and rare earth element compositions of zircons in the biotite leptynite and quartzite in the Guandu Group. Based on the mineral inclusions, internal structure, and U-Pb ages of zircons, the concordant $^{207}\text{Pb}/^{206}\text{Pb}$ age of 2 544 Ma or 2 536 Ma in the youngest group of detrital zircons is chosen as the maximal depositional timing of the Guandu Group. Combined with the geological relationship which the Guandu Group was intruded by the Huangcha granites, it is speculated that the depositional age of the Guandu Group wasn't Paleoproterozoic but late Neoproterozoic. Detrital zircon age patterns from the biotite leptynite and quartzite samples are similar and are characterized by the major peak of 2 512 Ma. Combined with the mineral inclusions and internal structure of the detrital zircons, it is suggested that the main provenance of the Guandu Group is the late Neoproterozoic intermediate-acid magmatic rocks. Two stage Hf isotopic model ages of detrital zircon reveals that the intensive crustal growth in the Zanzhuang Complex was concentrated from 2 850 Ma to 2 700 Ma. In addition, the new and published data from the Trans-North China Orogen reveal that the zircons in the Guandu Group recorded the consistent metamorphic age of ca. 2 500 Ma, similar to other complexes in the Trans-North China Orogen, indicating that the Trans-North China Orogen also experienced an intense regional metamorphism in ca. 2 500 Ma, which may be related to the late Neoproterozoic initial cratonization of the North China Craton.

Key words: Zanzhuang Complex; Guandu Group; leptynite; quartzite; detrital zircon

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华北克拉通中部造山带主要由太古宙-古元古代变质基底和中元古代-新生代的盖层组成(Zhao *et al.*, 2005, 2012; Zhao and Zhai, 2013; Tang and Santosh, 2018),带内早前寒武纪变质基底经历了长期而复杂的地质过程,较为全面地记录了华北克拉通太古宙-古元古代不同阶段的演化历史(Kusky and Li, 2003; Zhao *et al.*, 2005, 2012; Kröner *et al.*, 2005, 2006; Faure *et al.*, 2007; Zhang *et al.*, 2007, 2009; Trap *et al.*, 2009a, 2009b, 2012; Wang Z *et al.*, 2010; Diwu *et al.*, 2011; Zhai and Santosh, 2011, 2013; Du *et al.*, 2015, 2016a, 2016b, 2017; Wang J P *et al.*, 2015, 2017a, 2017b; Kusky *et al.*, 2016)。中部造山带太古宙-古元古代变质基底的深入研究,不仅对准确刻画华北克拉通早前寒武纪地质过程,而且对探究地球早期的动力学演变过程具有重要意义。赞皇杂岩位于华北克拉通中部造山带中南段东侧,是研究华北克拉通中部造山带新太古代-古元古代构造演化的关键地区,近年来备受关注,尤其是前人对赞皇地区新太古代-古元古代花岗岩类、古元古代变沉积岩(如甘陶河群)和古元古代变质作用都有较详细的研究(牛树银等, 1994; 杨崇辉等, 2011a, 2011b, 2015; Xiao *et al.*, 2011, 2014; Yang *et al.*, 2013; Du *et al.*, 2016b; Wang *et al.*, 2017a, 2017b; Zou *et al.*, 2021)。而针对官都岩群的研究较为薄弱,目前对官都岩群的形成时代与环境存在两种截然不同的认识,一种观点认为其形成于古元古代的被动大陆边缘(Li *et al.*, 2016; Tang *et al.*, 2016);而另一种观点认为官都岩群属于新太古代晚期混杂岩带(Wang *et al.*, 2017a, 2017b; Zhong *et al.*, 2021)。因此,本文以官都岩群中的黑云变粒岩与石英岩为研究对象,在野外地质观测与薄片观察的基础上,对其进行锆石矿物包体、U-Pb-Hf 同位素与稀土元素分析,以期进一步限定官都岩群的沉积时代,初步探讨赞皇杂岩新太古代晚期变质事件的地质意义。

1 地质概况

赞皇杂岩位于华北克拉通中部造山带中段东侧,北侧为阜平杂岩,东西宽 40 ~ 60 km,南北长约 140 km,总体呈纺锤形的北北东-南南西向展布(牛树银等, 1994; Trap *et al.*, 2012)。现有研究资料表明,赞皇杂岩新太古代-古元古代变质基底主要包括新太古代 TTG 片麻岩、新太古代晚期壳熔花岗岩质片麻岩、新太古代赞皇岩群、新太古代-古元古代官都岩群、古元古代甘陶河群和古元古代变基性

岩与花岗岩(河北省地质矿产局, 1989; 王岳军等, 2003; 杨崇辉等, 2011a, 2011b; Xie *et al.*, 2012; Yang *et al.*, 2013; Du *et al.*, 2016b)。近年来, 前人对该杂岩陆续进行了相关研究(Wang *et al.*, 2015, 2017a, 2017b; Tang *et al.*, 2016; Li *et al.*, 2016; 李伦等, 2017; Xiao *et al.*, 2021; Zou *et al.*, 2021)。其中, 新太古代 TTG 片麻岩主要为 2 750 ~ 2 700 Ma 英云闪长质片麻岩(Yang *et al.*, 2013)和 2 550 ~ 2 500 Ma 英云闪长质-花岗闪长质片麻岩(杨崇辉等, 2011b, 2015), 这些 TTG 片麻岩被解释为俯冲背景下板片熔融形成的(杨崇辉等, 2011b, 2015; Yang *et al.*, 2013); 而新太古代晚期壳熔花岗岩质片麻岩则指示同碰撞或后碰撞的构造环境(杨崇辉等, 2011b, 2015; Yang *et al.*, 2013), 并以黄岔岩体为代表, 该岩体呈岩株状出露于河北省邢台市西部山区, 主要由片麻状、似斑状二长花岗岩组成, 前人对该岩体开展了 LA-ICP-MS 锆石 U-Pb 测年, 获得岩体形成时代为 2 488 Ma(李伦等, 2017)。赞皇岩群主要呈残片状分布于 TTG 片麻岩中, 为一套中高级变质杂岩, 主要包括条带状黑云斜长/二长片麻岩、(石榴)斜长角闪岩与条带状石榴蓝晶黑云斜长/二长片麻岩等岩石(Xiao *et al.*, 2011, 2014; Zou *et al.*, 2021)。官都岩群呈 NE-SW 狭长的带状展布于赞皇杂岩中部, 主要包括(绿帘)斜长角闪岩、(透闪)大理岩、黑云变粒岩、(长石)石英岩以及少量石榴黑云斜长片麻岩与云母(石英)片岩等, 经历了高绿片岩相-高角闪岩相变质作用(王启超等, 2008; Trap *et al.*, 2009b; Zhong *et al.*, 2021)。甘陶河群出露于赞皇杂岩西北部, 呈近南北向分布, 主要岩石类型包括变质砂岩与变质玄武岩, 局部夹板岩与碳酸盐岩, 普遍遭受了绿片岩相变质(河北省地质矿产局, 1989; Liu *et al.*, 2012; Xie *et al.*, 2012; 杨崇辉等, 2015; Du *et al.*, 2016b), 根据甘陶河群变质中酸性火山岩与变质砂岩中锆石 U-Pb 定年结果, 甘陶河群的时代为 2 100 ~ 1 900 Ma(Du *et al.*, 2016b)。相关研究表明, 古元古代花岗岩主要分布于赞皇杂岩西北部(杨崇辉等, 2011a), 以许亭花岗岩最为典型, 呈岩基状侵入新太古代 TTG 片麻岩和赞皇岩群中, 主要由钾长花岗岩与二长花岗岩组成, 含少量钠长花岗岩, 无暗色包体, 偶见围岩的捕虏体, 局部含少量钾长石斑晶, 构成似斑状结构。SHRIMP 锆石 U-Pb 定年与地球化学研究结果表明, 许亭花岗岩侵位时代为

2 090 ~ 2 070 Ma, 具有 A 型花岗岩的地球化学特征, 可能形成于陆内裂谷环境(杨崇辉等, 2011a; Du *et al.*, 2016a)。

2 野外地质关系与岩石学特征

样品 21ZT20-1(黑云变粒岩)采自内丘县南赛乡萨岭村西北约 2.5 km 省道 S328 公路旁(图 1), 经纬度坐标为 37°20'13.45"(北纬)、114°16'32.64"(东经), 属于官都岩群下段(河北省地质矿产局, 1989)。如图 2 所示, 在省道 S328 公路旁约 100 m 范围内, 出露的主体为官都岩群黑云变粒岩和石英岩夹云母(石英)片岩; 在黑云变粒岩的露头上断续出露花岗质细脉, 有的花岗质细脉因遭受了强烈的剪切作用而透镜化; 在弱变形域, 黑云变粒岩或石英岩常分布有云母石英片岩薄层, 显示了变余粒序层理的特征。野外构造观测表明, 云母石英片岩片理倾向西偏北 310°, 倾角约为 20°。黑云变粒岩新鲜面呈灰白色, 细粒鳞片粒状变晶结构, 块状构造, 主要矿物包括钾长石、石英与黑云母, 钾长石以微斜长石为主, 含少量斜长石、电气石与钛铁矿(图 3), 副矿物主要包括锆石、独居石、磷钇矿、金红石与磷灰石。根据野外产状与矿物组成特征, 推测其原岩为泥砂质沉积岩。

样品 21ZT22-1(石英岩)采自邢台县北小庄镇雀寨村东约 3 km 板车山路旁(图 1), 经纬度坐标为 37°17'41.88"(北纬)、114°10'35.83"(东经), 亦属于官都岩群下段(河北省地质矿产局, 1989)。如图 2 所示, 该点石英岩先后至少经历了两期变形作用, 早期变形以形成露头尺度的同斜紧闭褶皱为特征, 野外可见其轴面发生弯曲, 并叠加了第 2 期宽缓褶皱; 第 2 期构造变形以形成相对较大的宽缓褶皱与窗棂构造为特征, 并伴随有花岗伟晶岩的侵入。石英岩新鲜面为灰白色, 中细粒粒状变晶结构, 块状构造, 局部因强烈的剪切与挤压变形, 片理构造与宽缓褶皱较为发育, 其主要组成矿物为石英, 含少量斜长石(图 3), 副矿物主要包括锆石、独居石、磷钇矿、金红石和磷灰石。

官都岩群石英岩与黄岔岩体以韧性剪切构造接触为主, 在接触界线附近, 官都岩群的石英岩和黄岔岩体均发生了强烈的韧性剪切变形, 形成了典型的糜棱岩带(李伦等, 2017), 如图 2f~2i 所示, 但局部仍可见黄岔花岗岩侵入并包裹官都岩群石英岩

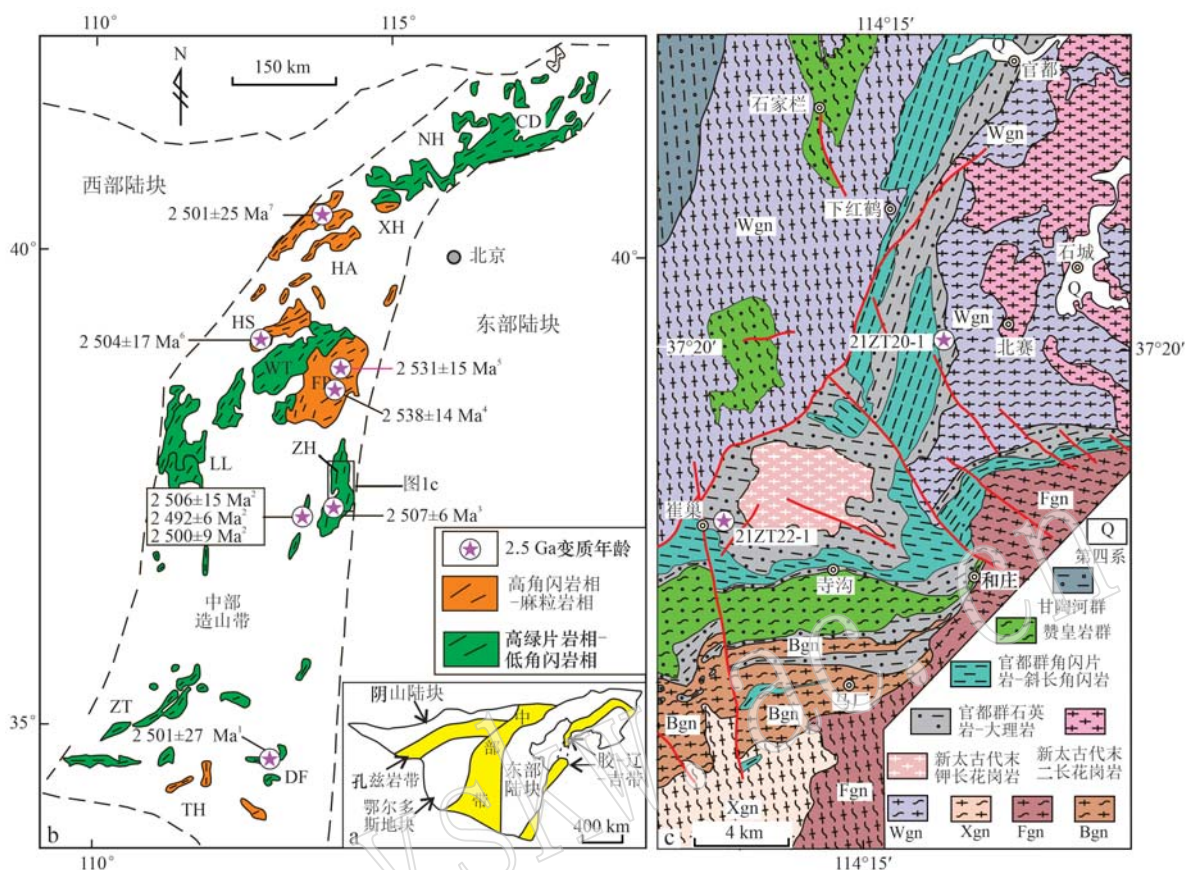


图1 华北克拉通中部造山带(a, b, Zhao *et al.*, 2005)与赞皇杂岩(c, 王启超等, 2008)前寒武纪地质简图

Fig. 1 Simplified geological map of the Trans-North China Orogen (a, b, Zhao *et al.*, 2005) and Zhanhuang Complex

(c, Wang Qichao *et al.*, 2008) in the North China Craton showing the exposure of Archaean to Paleoproterozoic basement rocks
图1b中变质杂岩缩写: CD—承德变质杂岩; NH—冀北变质杂岩; XH—宣化变质杂岩; HA—怀安变质杂岩; HS—衡山变质杂岩; WT—五台变质杂岩; FP—阜平变质杂岩; LL—吕梁变质杂岩; ZH—赞皇变质杂岩; ZT—中条山变质杂岩; DF—登封变质杂岩; TH—太华变质杂岩; 图1b中数据来源: 1—Huang *et al.* (2020); 2—肖玲玲等 (2019); 3—Xiao *et al.* (2014); 4—王建龙等 (2020); 5—程裕淇等 (2004); 6—Qian and Li (2021); 7—刘平华等 (未发表数据); 图1c中变质侵入体缩写: Wgn—王家寨片麻岩; Xgn—西黄村片麻岩; Fgn—丰来峪片麻岩; Bgn—白虎庄片麻岩

the abbreviation of the metamorphic complex in Fig. 1b as follows: CD—Chengde Complex; NH—Jibei Complex; XH—Xuanhua Complex; HA—Huai'an Complex; HS—Hengshan Complex; WT—Wutai Complex; FP—Fuping Complex; LL—Lüliang Complex; ZH—Zanhuang Complex; ZT—Zhongtiaoshan Complex; DF—Dengfeng Complex; TH—Taihua Complex; the age data in Fig. 1b are cited by the following references: 1—Huang *et al.* (2020); 2—Xiao Lingling *et al.* (2019); 3—Xiao *et al.* (2014); 4—Wang Jianlong *et al.* (2020); 5—Cheng Yuqi *et al.* (2004); 6—Qian and Li (2021); 7—Liu Pinghua *et al.* (unpublished data); the metamorphic intrusions in Fig. 1c are abbreviated as follows: Wgn—Wangjia-chong orthogneiss; Xgn—Xihuangcun orthogneiss; Fgn—Fenglaiyu orthogneiss; Bgn—Baihuazhuang orthogneiss

和细粒黑云斜长片麻岩,表明官都岩群与黄岔岩体原来应为侵入接触关系。

3 分析方法

对黑云变粒岩和石英岩样品进行了锆石 U-Pb 测年、锆石稀土元素分析、锆石 TIMA 矿物包体鉴定和锆石 Hf 同位素测试。锆石分选在河北省区域地质矿产调查研究所实验室完成。锆石靶制备完成后,对锆石颗粒进行透射光和反射光显微照片的拍摄,以便了解锆石颗粒含包裹体和表面裂纹发育的

情况。最后将锆石靶镀金,进行阴极发光图像(CL)照相以便观察锆石内部结构。锆石阴极发光图像(CL)拍摄在南京宏创地质勘查技术服务有限公司利用 TESCAN 场发射扫描电镜(型号 MIRA 3LMH)完成,实验过程中加速电压 8 kV,吸收电流 1.2 nA,每 80 s 扫描一次。锆石内部矿物包体 TIMA 分析在南京宏创地质勘查技术服务有限公司采用配有 4 个能谱探头(EDAX Element 30)的 Mira-3 扫描电镜完成,锆石靶在实验前进行喷碳,实验中加速电压 25 kV,电流 9 nA,工作距离 15 mm,电流和 BSE 信号强度使用铂法拉第杯自动程序校准,EDS 信号

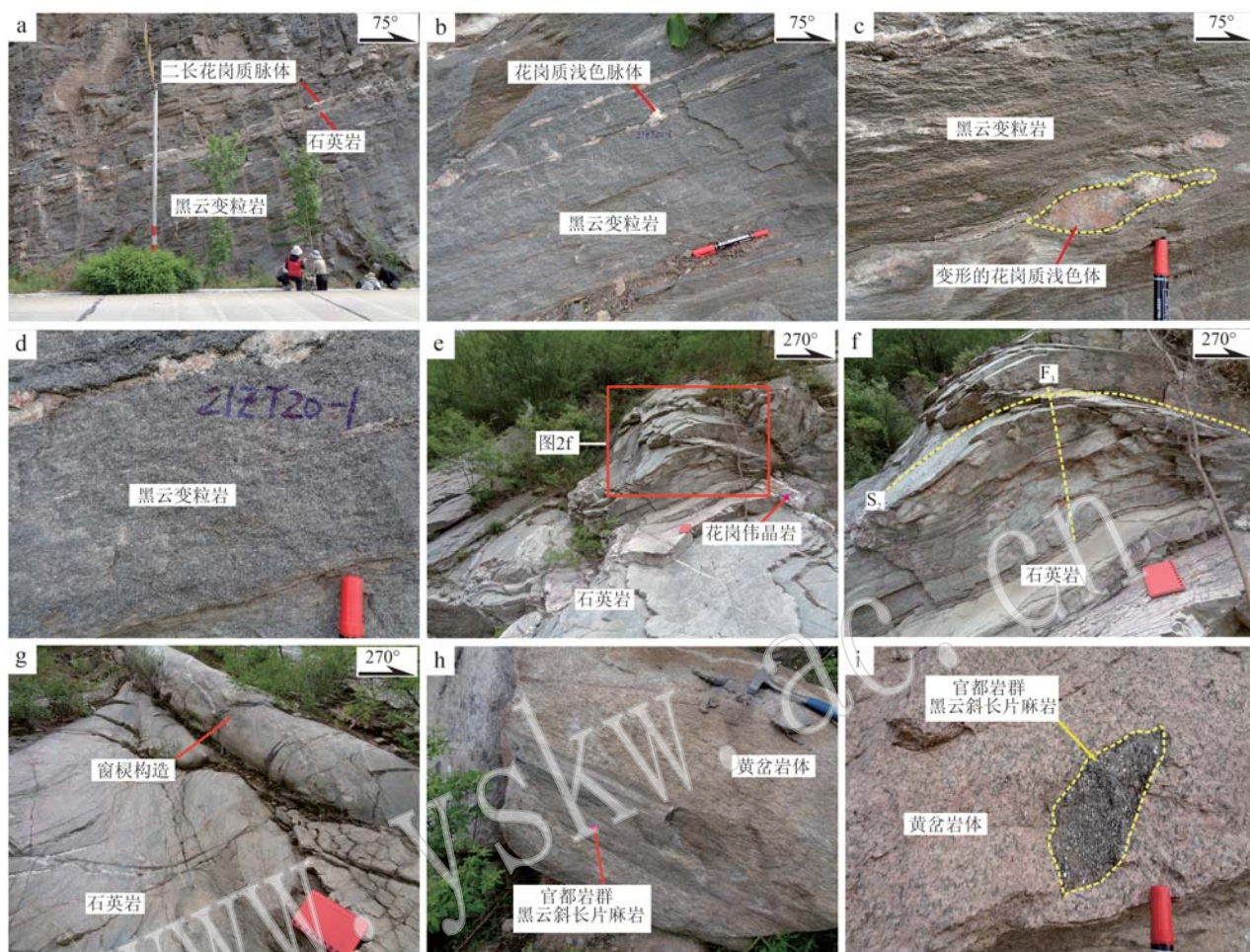


图2 赞皇杂岩官都岩群黑云变粒岩与石英岩野外露头照片

Fig. 2 Field photographs showing the outcrops of the biotite leptynite and quartzite from the Guandu Group in the Zanzhuang Complex

a, b—官都岩群石英岩、黑云变粒岩与花岗质浅色脉体的野外远景与近景照片；c—官都岩群黑云变粒岩中变形的花岗质构造透镜体的野外露头近照；d—官都岩群中黑云变粒岩的露头近照；e, f—官都岩群石英岩中宽缓褶皱远景与近景照片；g—官都岩群石英岩中窗棂构造远景照片；h, i—黄盆岩体中官都岩群黑云斜长片麻岩包体的露头近照

a, b—the far and near field photographs showing the quartzite with biotite leptynite of the Guandu Group was intruded by the granitic veins; c—the field photographs showing the granitic veins within the with biotite leptynite of the Guandu Group was deformed and lentoid; d—the field photographs showing biotite leptynite of the Guandu Group was fine-grained and massive; e, f—the far and near field photographs showing the quartzites of the Guandu Group have undergone compression deformation and formed rolling fold; g—the field photographs showing the mullion structure of the quartzites of the Guandu Group; h, i—the field potographs showing the biotite plagioclase gneisses of the Guandu Group as xenoliths within the Huangcha Pluton

使用 Mn 标样校准。测试中使用解离模式，同时获取 BSE 图和 EDS 数据，每个点的 X 射线计数为 1 000。像素大小 3 μm ，能谱步长 9 μm 。

锆石 U-Pb 定年与稀土元素分析在南京宏创地质勘查技术服务有限公司完成。激光剥蚀平台采用 Resolution SE 型 193 nm 深紫外激光剥蚀进样系统 (Applied Spectra, 美国)，配备 S155 型双体积样品池。质谱仪采用 Agilent 7900 型电感耦合等离子体

质谱仪 (Agilent, 美国)。详细的调谐参数见 Thompson 等 (2018)，采用束斑直径 30 μm 、剥蚀频率 10 Hz、能量密度 3.5 J/cm²、扫描速度 3 $\mu\text{m/s}$ 的激光参数剥蚀 NIST 612，调节气流以获得高的信号强度 ($^{238}\text{U} \sim 6 \times 10^5$ cps)、低的氧化物产率 (ThO/Th < 0.2%)。锆石 U-Pb 年龄数据处理采用 Iolite 程序 (Paton *et al.*, 2010)，锆石 91500 作为校正标样，GJ-1 作为监测标样，每隔 10~12 个样品点分析 2 个

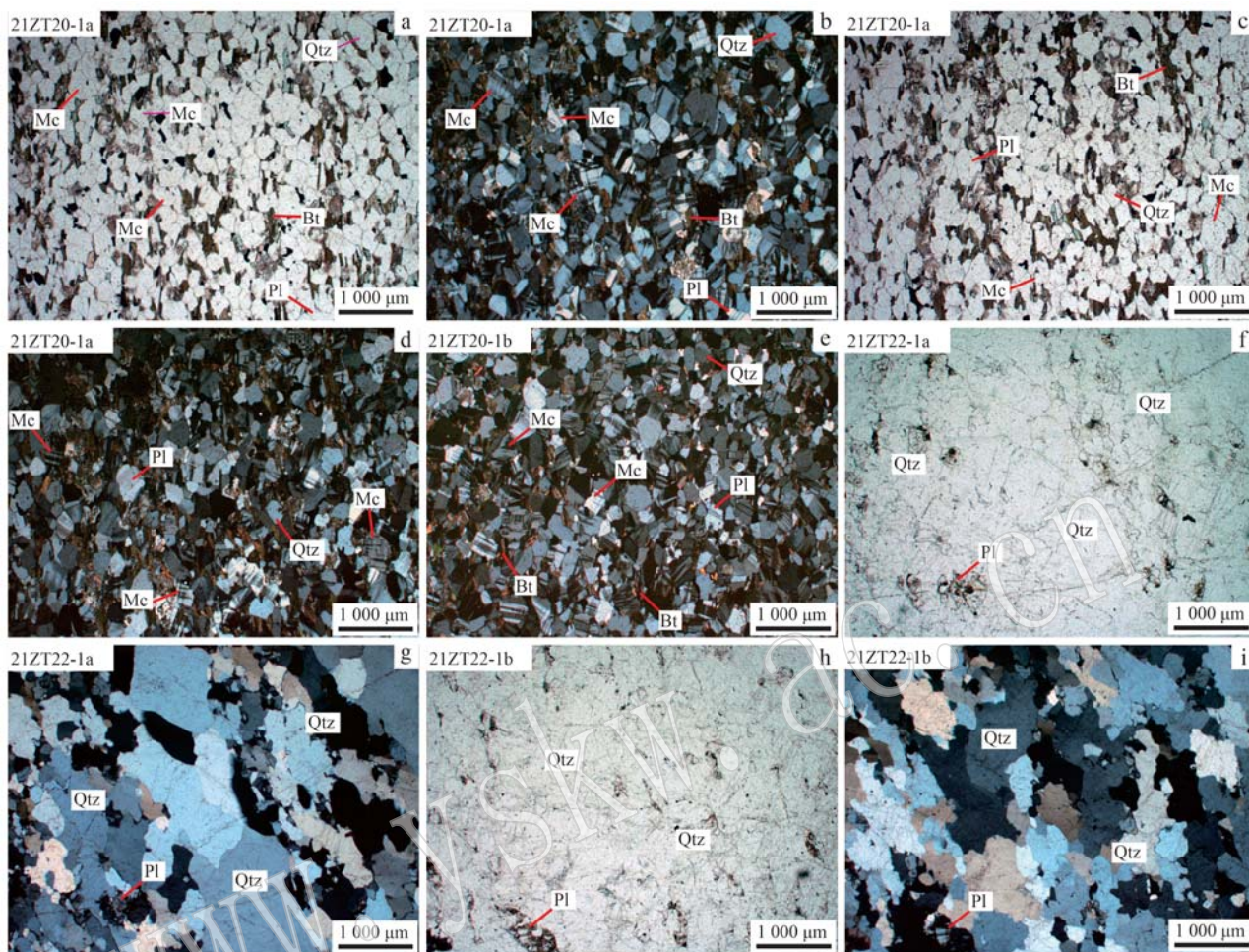


图3 赞皇杂岩官都岩群黑云变粒岩与石英岩代表性显微照片(矿物缩写据沈其韩, 2009)

Fig. 3 Representative photomicrographs of the biotite leptynite and quartzite from the Guandu Group in the Zanzhuang Complex (mineral abbreviation after Shen Qihan, 2009)

a, b, c, d, e—官都岩群细粒黑云变粒岩主要变质矿物: 石英(Qtz)+微斜长石(Mc)+斜长石(Pl)+黑云母(Bt), a, c为单偏光; b, d, e为正交偏光; f, h—官都岩群中石英岩中主要矿物石英(Qtz)与微量矿物斜长石(Pl), 单偏光; g, i—官都岩群石英岩中主要

矿物石英(Qtz)以及石英岩缝合线构造, 正交偏光

a, b, c, d, e—typical photomicrographs showing the main mineral assemblage of quartz + microcline + plagioclase + biotite identified in the biotite leptynite of the Guandu Group, a and c are aplane polarized light (PPL), b, d and e are cross-polarized light (CPL); f, h—the main and minor mineral is quartz and plagioclase in the quartzite from the Guandu Group, respectively, PPL; g, i—the main and minor mineral is quartz and plagioclase in the quartzite from the Guandu Group, respectively, CPL

91500 标样及 1 个 GJ-1 标样。通常采集 20 s 的气体空白、35 ~ 40 s 的信号区间进行数据处理, 按指数方程进行深度分馏校正(Paton *et al.*, 2010)。以 NIST 610 作为外标, ^{91}Zr 作为内标计算微量元素含量。

锆石 Lu-Hf 同位素分析在南京大学内生金属与成矿机制国家重点实验室完成。分析过程中, 能量密度 6.0 J/cm^2 , 束斑直径 $50 \text{ }\mu\text{m}$, 频率 8 Hz, 共剥蚀 40 s, 剥蚀气溶胶由氦气送入 MC-ICP-MS 完成测试。测试过程中每隔 10 颗样品锆石交替测试 2 颗标准锆石(包括 GJ-1、91500、Plešovice、Mud Tank、

Penglai), 以检验锆石 Hf 同位素比值数据质量。

锆石 Hf 同位素数据处理过程: 首先采用 $^{179}\text{Hf}/^{177}\text{Hf}=0.7325$ 获得 Hf 同位素质量歧视因子 β_{Hf} ; 通过锆石自身的 $^{172}\text{Yb}/^{173}\text{Yb}$ 实测数据, 获得 Yb 同位素质量歧视因子 β_{Yb} , 再采用 $^{176}\text{Yb}/^{172}\text{Yb}=0.5887$ (Vervoort *et al.*, 2004) 扣除 ^{176}Yb 对 ^{176}Hf 的同量异位干扰; 由于 Lu 只有 ^{175}Lu 与 ^{176}Lu 两个同位素, 因此假定 $\beta_{\text{Lu}}=\beta_{\text{Hf}}$, 再采用 $^{176}\text{Lu}/^{175}\text{Lu}=0.02655$ (Vervoort *et al.*, 2004) 扣除 ^{176}Lu 对 ^{176}Hf 的同质异位干扰。

4 锆石阴极发光图像特征

黑云变粒岩样品(21ZT20-1)中的锆石颗粒相对较小,其粒度为50~140 μm ,呈紫红色,以短柱状晶形为主,少数颗粒为不规则状晶形,长宽比为1:1~2.5:1。在锆石阴极发光图像中(图4),绝大多数碎屑锆石具有中等发光效应(灰色-灰白色),并可

见较为清晰的岩浆韵律环带,少数锆石核部环带明显被切割或熔蚀(图4i)。锆石阴极发光图像、背散射电子图像与TIMA矿物相扫描分析表明(图5),发育岩浆韵律环带的核部含有少量长英质矿物包体,主要包括石英、钾长石、斜长石与磷灰石(图5),尤其是在有的岩浆型碎屑锆石内部鉴别出钾长石+石英+斜长石的多相矿物包体,进一步证明这些锆石是从花岗质岩浆中晶出的。

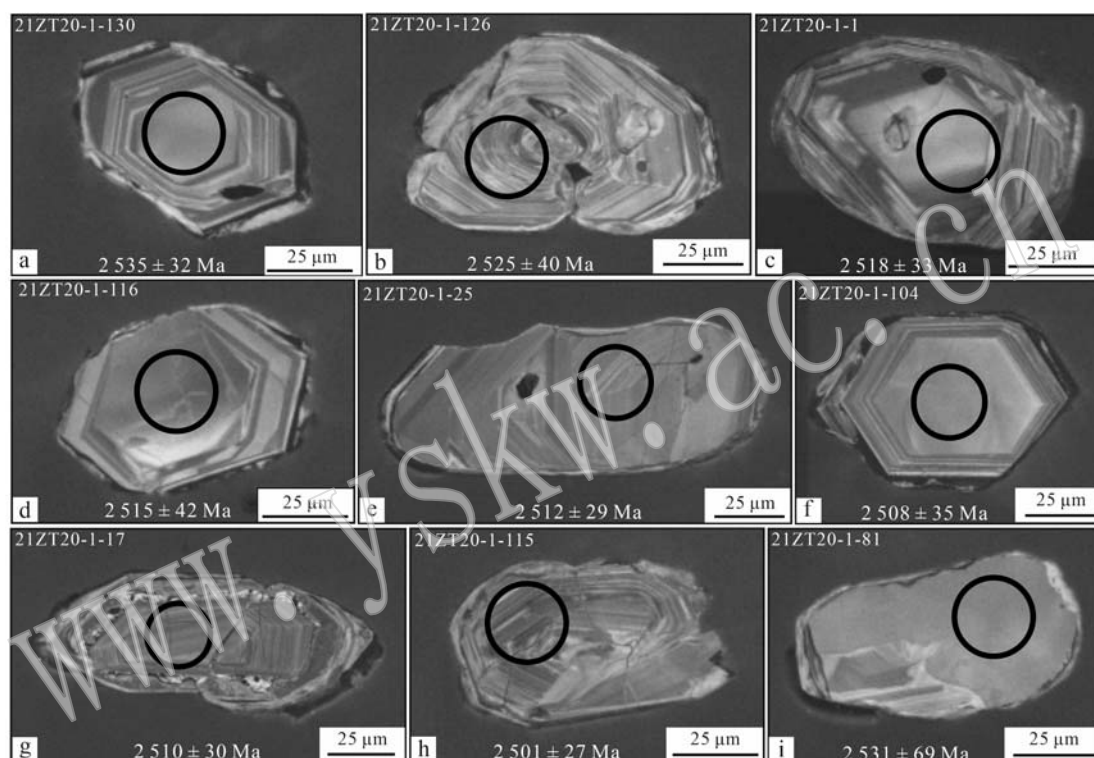


图4 赞皇杂岩官都岩群黑云变粒岩中锆石阴极发光图像与 $^{207}\text{Pb}/^{206}\text{Pb}$ 年龄

Fig. 4 Cathodoluminescence images and $^{207}\text{Pb}/^{206}\text{Pb}$ ages of zircons from the biotite leptynite from the Guandu Group in the Zanzhuang Complex

石英岩(21ZT22-1)中的锆石颗粒相对较大,其粒度为80~280 μm ,呈紫红色,多数为长柱状晶形,少数为浑圆状晶形,长宽比介于1:1~3:1之间。从石英岩锆石的阴极发光图像特征来看(图6),多数锆石为长柱状晶形,从核部至边部具有相对中等的发光效应(灰色),普遍发育典型的岩浆韵律环带结构,有的岩浆型碎屑锆石核部明显被切割或熔蚀,显示了变质重结晶锆石的特征(图6i;吴元保等,2004)。少数锆石具有相对强的发光效应(灰白色),并发育十分典型的板状环带结构(图6),显示了高温岩浆锆石的特征。锆石阴极发光图像、背散射电子图像与TIMA矿物相扫描分析表明(图7),

石英岩中有的锆石含有长英质矿物包体,主要包括钾长石、石英、斜长石、绿泥石、黑云母、磁铁矿与磷灰石(图7),与样品21ZT20-1类似,在样品21ZT22-1中有的锆石中鉴别出钾长石+石英+绿泥石+黑云母+磁铁矿的多相矿物包体,证明这些锆石是从花岗质岩浆中晶出的。

5 锆石 U-Pb 年龄

对黑云变粒岩(21ZT20-1)中锆石进行了U-Pb测年,共分析了130个锆石测点,获得了125个有效年龄,其分析结果见表1与图8a。依据分析点的

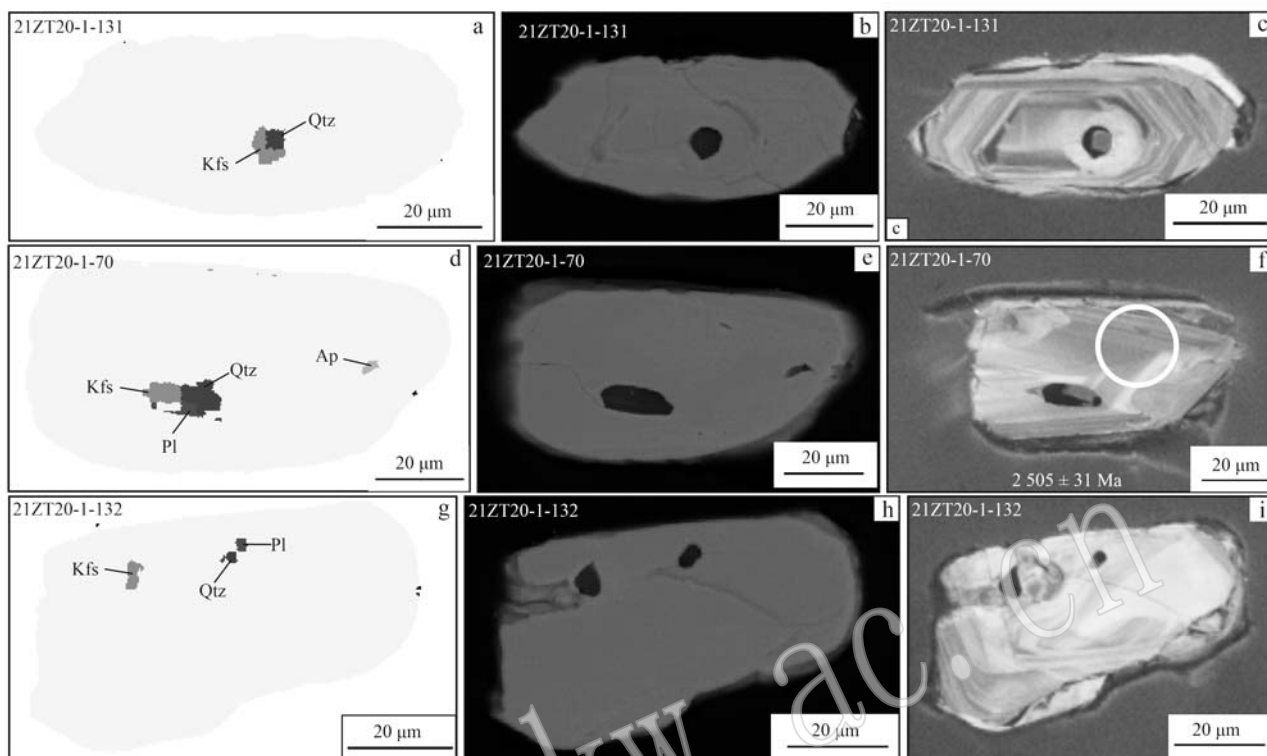


图5 赞皇杂岩官都岩群黑云变粒岩中锆石代表性矿物包体的矿物相图(a、d、g)、背散射电子图像(b、e、h)与阴极发光图像(c、f、i)

Fig. 5 Representative mineral phase (a, d, g), backscatter electron (b, e, h), and cathodoluminescence images (c, f, i) showing mineral inclusions of zircons from the biotite leptynite in the Guandu Group of the Zanhuan Complex

a, b, c—第131粒岩浆型碎屑锆石, 继承性岩浆型碎屑锆石核部含有钾长石(Kfs)+石英(Qtz)的多相矿物包体; d, e, f—第70粒岩浆型碎屑锆石, 岩浆型碎屑锆石核部含有钾长石(Kfs)+石英(Qtz)+斜长石(Pl)+磷灰石(Ap)的多相矿物包体; g, h, i—第132粒碎屑锆石, 岩浆型碎屑锆石内部含有钾长石(Kfs)+石英(Qtz)+斜长石(Pl)的多相矿物包体

a, b, c—zircon grain 21ZT20-1-131 showing multiphase mineral inclusions of K-feldspar + quartz were identified in the magmatic-type detrital zircon domain; d, e, f—zircon grain 21ZT20-1-70 showing multiphase mineral inclusions of K-feldspar + quartz + plagioclase were identified in the magmatic-type detrital zircon domain; g, h, i—zircon grain 21ZT20-1-132 showing multiphase mineral inclusions of K-feldspar + quartz + plagioclase were identified in the magmatic-type detrital zircon domain

锆石阴极发光图像与U-Pb年龄结果, 125个锆石微区的 $^{207}\text{Pb}/^{206}\text{Pb}$ 年龄可进一步划分2组。其中, 第1组123个碎屑锆石的Th与U含量变化较大, 分别为 $18.20 \times 10^{-6} \sim 981.00 \times 10^{-6}$ 与 $38.80 \times 10^{-6} \sim 563.00 \times 10^{-6}$, 相应的Th/U为0.24~2.44。如图8a所示, 大部分该组锆石获得的 $^{207}\text{Pb}/^{206}\text{Pb}$ 年龄比较分散, 介于 $2574 \pm 27 \text{ Ma} \sim 2434 \pm 97 \text{ Ma}$ 之间, 构成的不一致上交点年龄为 $2521 \pm 5 \text{ Ma}$, 略小于位于谐和线附近的15个最大的 $^{207}\text{Pb}/^{206}\text{Pb}$ 加权平均年龄($2544 \pm 9 \text{ Ma}$), 大致代表该组锆石的形成时代下限。此外, 2个变质重结晶锆石的Th、U含量分别为 $28.70 \times 10^{-6} \sim 82.50 \times 10^{-6}$ 与 $59.60 \times 10^{-6} \sim 141.40 \times 10^{-6}$, 相应的Th/U值为0.48~0.58(表1)。2个测

点获得的 $^{207}\text{Pb}/^{206}\text{Pb}$ 年龄相对集中(图8), 分别为 $2519 \pm 40 \text{ Ma}$ 与 $2531 \pm 69 \text{ Ma}$ (表1)。

选择了石英岩(21ZT22-1)中156粒锆石进行U-Pb测年, 共分析了160个测点的U-Pb同位素测试, 获得了160个有效年龄, 其分析结果见表2与图8b。依据分析点的锆石阴极发光图像与U-Pb年龄结果, 160个锆石微区的 $^{207}\text{Pb}/^{206}\text{Pb}$ 年龄可进一步划分3组。其中, 第1组2个新太古代早期碎屑锆石的Th、U含量分别为 48.20×10^{-6} 、 79.20×10^{-6} 与 46.10×10^{-6} 、 150.00×10^{-6} , 相应的Th/U值分别为0.53与1.05, 2个测点的 $^{207}\text{Pb}/^{206}\text{Pb}$ 年龄分别为 $2677 \pm 20 \text{ Ma}$ 与 $2671 \pm 32 \text{ Ma}$; 第2组146个新太古代晚期碎屑锆石的Th与U含量变化较大, Th、U含量

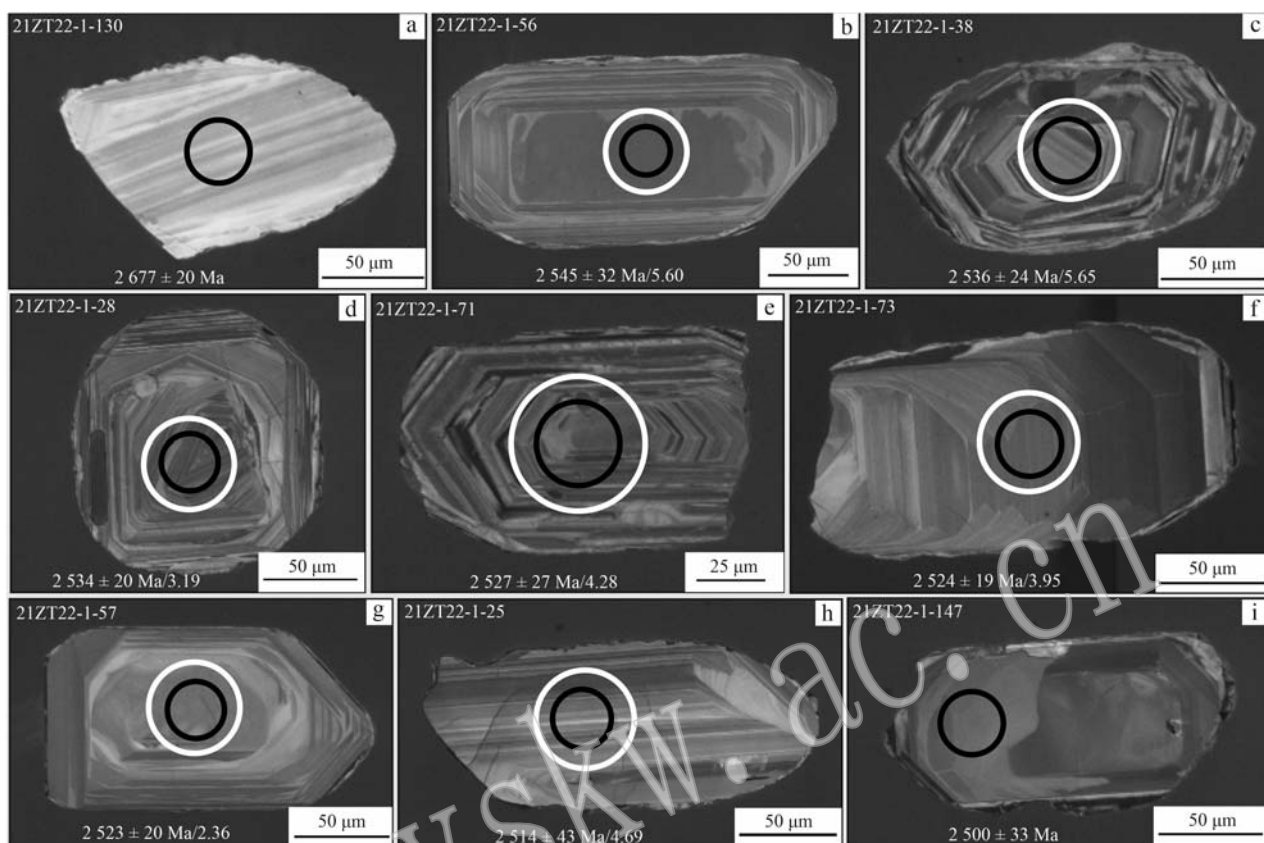


图6 赞皇杂岩官都岩群石英岩中锆石阴极发光图像、 $^{207}\text{Pb}/^{206}\text{Pb}$ 年龄与 $\epsilon_{\text{Hf}}(t)$ 值(黑色与白色圆圈分别为 U-Pb 和 Lu-Hf 同位素分析点位置)

Fig. 6 Cathodoluminescence images, $^{207}\text{Pb}/^{206}\text{Pb}$ ages and $\epsilon_{\text{Hf}}(t)$ values of zircons from the quartzite in the Guandu Group of the Zhanhuang Complex (the black and white circles are U-Pb and Lu-Hf isotope analysis points, respectively)

分别为 $10.30 \times 10^{-6} \sim 1\,433.00 \times 10^{-6}$ 与 $17.50 \times 10^{-6} \sim 690.00 \times 10^{-6}$, 相应的 Th/U 值为 $0.07 \sim 3.11$ 。如图 8b 所示, 该组锆石获得的 $^{207}\text{Pb}/^{206}\text{Pb}$ 年龄相对分散, 介于 $2\,552 \pm 29 \text{ Ma} \sim 2\,467 \pm 51 \text{ Ma}$ 之间, 构成的不一致上交点年龄为 $2\,512 \pm 3 \text{ Ma}$, 略小于位于谐和线附近 15 个最大的 $^{207}\text{Pb}/^{206}\text{Pb}$ 加权平均年龄 ($2\,536 \pm 6 \text{ Ma}$), 大致代表该组锆石的形成时代下限; 第 3 组 12 个变质重结晶锆石 Th 与 U 含量分别为 $22.50 \times 10^{-6} \sim 674.20 \times 10^{-6}$ 与 $57.70 \times 10^{-6} \sim 319.60 \times 10^{-6}$, 相应的 Th/U 值为 $0.32 \sim 2.11$ (表 2), 12 个测点获得的 $^{207}\text{Pb}/^{206}\text{Pb}$ 年龄为 $2\,527 \pm 25 \text{ Ma}$ 至 $2\,464 \pm 41 \text{ Ma}$, 对应的加权平均年龄为 $2\,501 \pm 10 \text{ Ma}$ (图 8c)。

6 锆石稀土元素组成与特征

对黑云变粒岩(21ZT20-1)与石英岩(21ZT22-1)中锆石分别进行了 125 个与 160 个测点的稀土元素

化学成分分析, 其分析结果见表 3、表 4, 稀土元素配分曲线如图 8 所示。

如图 8 与表 3 所示, 黑云变粒岩中 123 个碎屑锆石的稀土元素总含量变化范围较大, 介于 $209.47 \times 10^{-6} \sim 2\,398.52 \times 10^{-6}$ 之间(图 8b, 表 3), 从球粒陨石标准化稀土元素配分曲线特征可以明显看出, 123 个碎屑锆石测点具有轻稀土元素相对亏损, 而重稀土元素相对富集的特征, 但不同测点轻稀土元素亏损与重稀土元素富集程度存在一些差异, 其 Lu_N/Sm_N 值变化较大, 为 $8.62 \sim 299.91$; 123 个碎屑锆石具有正 Ce 异常与负 Eu 异常, 但不同测点存在明显差异, Ce/Ce^* 值为 $1.54 \sim 212.02$, Eu/Eu^* 值为 $0.08 \sim 2.30$ 。2 个变质锆石测点稀土元素总含量变化较小, 分别为 512.55×10^{-6} 与 987.45×10^{-6} ; 从球粒陨石标准化稀土元素配分曲线特征可以明显看出, 2 个变质成因的锆石轻稀土元素明显亏损, 而重稀土元素明显富集, 相应的稀土元素配分模式

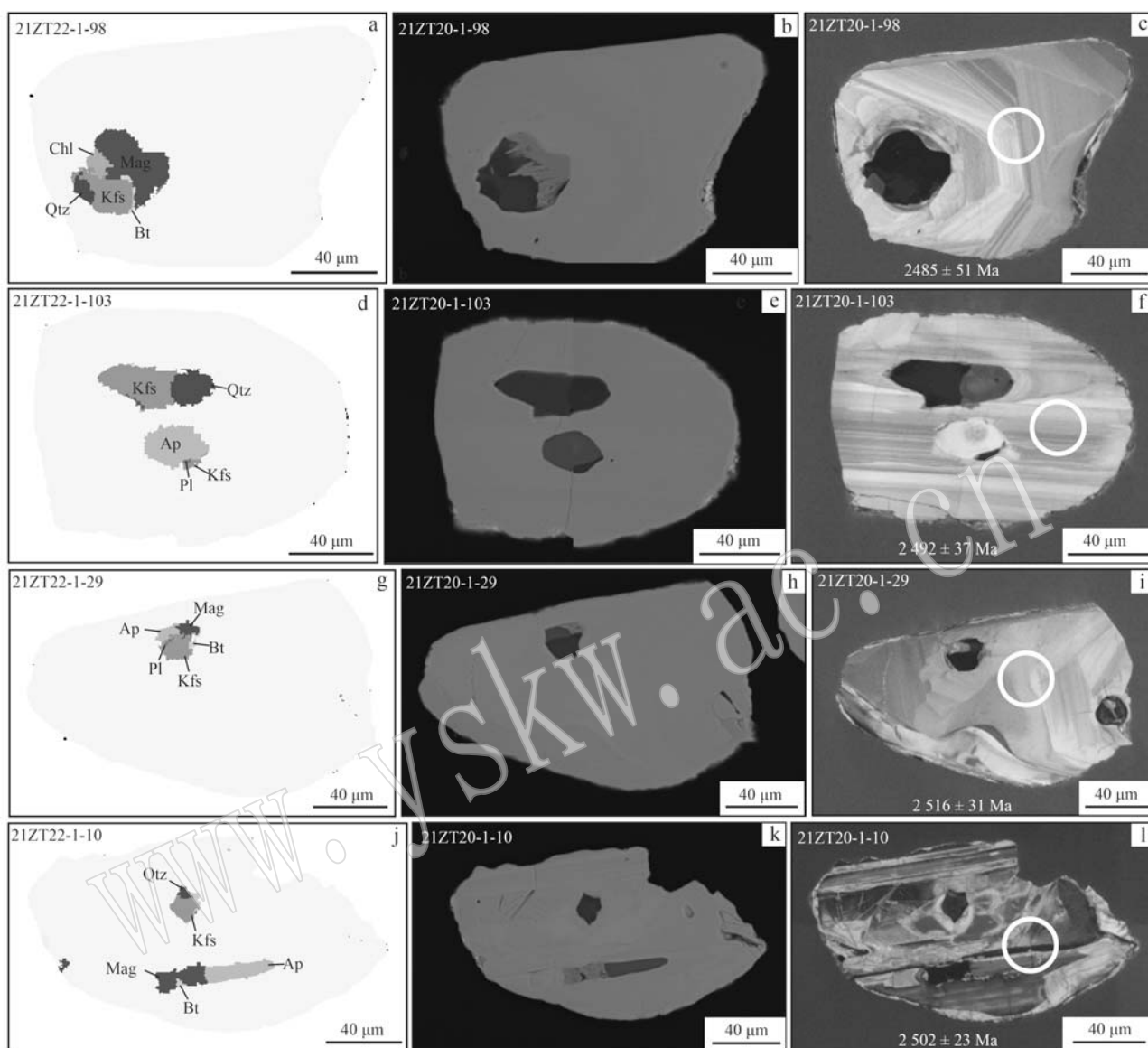


图7 赞皇杂岩官都岩群石英岩中锆石代表性矿物包体的矿物相图(a, d, g, j)、背散射电子图像(b, e, h, k)与阴极发光图像(c, f, i, l)

Fig. 7 Representative mineral phase (a, d, g, j), backscatter electron (b, e, h, k), and cathodoluminescence images (c, f, i, l) showing mineral inclusions of zircons from the quartzite from the Guandu Group in the Zanzhuang Complex

a, b, c—第98粒岩浆型碎屑锆石, 继承性岩浆型碎屑锆石含有钾长石(Kfs)+石英(Qtz)+黑云母(Bt)+绿泥石(Chl)+磁铁矿(Mag)的多相矿物包体; d, e, f—第103粒岩浆型碎屑锆石, 岩浆型碎屑锆石含有钾长石(Kfs)+石英(Qtz)+斜长石(Pl)+磷灰石(Ap)的多相矿物包体; g, h, i—第29粒岩浆型碎屑锆石, 岩浆型碎屑锆石含有钾长石(Kfs)+黑云母(Bt)+斜长石(Pl)+磷灰石(Ap)+磁铁矿(Mag)的多相矿物包体; j, k, l—第10粒岩浆型碎屑锆石, 岩浆型碎屑锆石含有钾长石(Kfs)+黑云母(Bt)+石英(Qtz)+磷灰石(Ap)+磁铁矿(Mag)的多相矿物包体

a, b, c—zircon grain 21ZT22-1-98 showing multiphase mineral inclusions of K-feldspar + quartz + biotite + chlorite + magnetite were identified in the magmatic-type detrital zircon domain; d, e, f—zircon grain 21ZT22-1-103 showing multiphase mineral inclusions of K-feldspar + quartz + plagioclase + apatite were identified in the magmatic-type detrital zircon domain; g, h, i—zircon grain 21ZT22-1-29 showing multiphase mineral inclusions of K-feldspar + biotite + plagioclase + apatite + magnetite were identified in the magmatic-type detrital zircon domain; j, k, l—zircon grain 21ZT22-1-10 showing multiphase mineral inclusions of K-feldspar + biotite + quartz + apatite + magnetite were identified in the magmatic-type detrital zircon domain

表 1 赞皇杂岩官都岩群黑云变粒岩锆石 LA-ICP-MS U-Pb 测试结果
Table 1 LA-ICP-MS zircon U-Pb dating results of the biotite leptynites of the Guandu Group in the Zanzhuang Complex

样品号	$w_B/10^{-6}$			Th/U	同位素比值				年龄/Ma				谐和度/%				
	Total Pb	^{232}Th	^{238}U		$^{207}\text{Pb}/^{235}\text{U}$	2σ	$^{206}\text{Pb}/^{238}\text{U}$	2σ	$^{207}\text{Pb}/^{206}\text{Pb}$	2σ							
岩浆型碎屑锆石																	
21ZT20-1-5	138.70	146.00	213.90	0.68	11.300 0	0.380 0	0.487 3	0.009 2	0.172 1	0.006 5	2 546	32	2 558	40	2 574	27	100
21ZT20-1-2	55.80	51.50	85.30	0.60	10.940 0	0.370 0	0.474 3	0.007 8	0.170 6	0.006 5	2 514	32	2 501	34	2 556	30	99
21ZT20-1-9	113.30	90.00	170.20	0.53	11.290 0	0.380 0	0.491 9	0.007 9	0.169 8	0.006 5	2 544	31	2 578	34	2 550	29	99
21ZT20-1-90	132.50	139.30	200.60	0.69	10.990 0	0.350 0	0.472 9	0.007 8	0.169 8	0.006 3	2 520	29	2 495	34	2 550	26	99
21ZT20-1-83	157.20	149.60	228.40	0.65	10.900 0	0.420 0	0.470 9	0.009 8	0.169 5	0.007 0	2 512	36	2 487	43	2 547	39	99
21ZT20-1-38	57.70	59.40	83.40	0.71	11.250 0	0.480 0	0.468 0	0.009 8	0.170 8	0.008 6	2 537	40	2 473	43	2 545	63	97
21ZT20-1-12	56.00	58.60	82.40	0.71	11.080 0	0.380 0	0.486 4	0.009 0	0.168 8	0.006 5	2 527	32	2 553	39	2 539	31	99
21ZT20-1-77	212.10	356.00	295.30	1.21	11.050 0	0.360 0	0.482 7	0.008 9	0.168 4	0.006 4	2 526	31	2 538	39	2 539	29	100
21ZT20-1-129	105.20	107.60	173.00	0.62	9.190 0	0.590 0	0.393 0	0.021 0	0.168 5	0.007 1	2 345	58	2 130	95	2 536	44	90
21ZT20-1-110	95.80	156.40	126.90	1.23	10.960 0	0.440 0	0.478 0	0.011 0	0.168 2	0.007 0	2 517	37	2 516	49	2 535	40	100
21ZT20-1-130	59.30	39.60	89.00	0.44	11.320 0	0.390 0	0.494 1	0.008 4	0.168 5	0.006 6	2 546	32	2 587	36	2 535	32	98
21ZT20-1-58	73.50	79.70	104.50	0.76	11.540 0	0.490 0	0.486 1	0.010 0	0.168 1	0.007 5	2 565	39	2 553	44	2 533	48	100
21ZT20-1-19	91.50	114.40	160.20	0.71	9.730 0	0.360 0	0.429 1	0.008 8	0.167 8	0.006 5	2 407	34	2 300	40	2 531	31	95
21ZT20-1-36	77.50	70.80	117.40	0.60	11.120 0	0.410 0	0.480 7	0.010 0	0.167 8	0.006 6	2 530	34	2 529	44	2 531	32	100
21ZT20-1-59	65.60	34.50	98.00	0.35	11.220 0	0.490 0	0.484 0	0.011 0	0.167 8	0.007 2	2 538	40	2 543	47	2 530	43	100
21ZT20-1-123	125.10	160.60	186.10	0.86	9.910 0	0.430 0	0.420 0	0.013 0	0.167 8	0.007 0	2 420	40	2 258	59	2 529	40	93
21ZT20-1-3	154.10	130.70	234.20	0.56	11.190 0	0.400 0	0.481 6	0.010 0	0.167 8	0.006 5	2 543	30	2 531	45	2 528	31	100
21ZT20-1-82	139.70	163.90	199.60	0.82	11.070 0	0.360 0	0.482 2	0.007 9	0.167 6	0.006 5	2 527	31	2 542	32	2 528	31	99
21ZT20-1-124	60.90	40.60	94.00	0.43	11.150 0	0.420 0	0.483 7	0.008 4	0.167 8	0.006 9	2 531	35	2 542	36	2 528	39	100
21ZT20-1-88	128.50	159.60	191.10	0.84	10.550 0	0.370 0	0.456 6	0.010 0	0.166 6	0.006 4	2 482	32	2 423	45	2 527	27	98
21ZT20-1-89	131.70	119.30	198.20	0.60	10.740 0	0.420 0	0.467 0	0.011 0	0.167 5	0.007 2	2 498	38	2 470	48	2 527	45	99
21ZT20-1-102	111.20	126.30	159.00	0.79	11.080 0	0.370 0	0.480 6	0.007 9	0.167 6	0.006 3	2 526	31	2 529	34	2 527	28	100
21ZT20-1-117	71.90	88.40	103.40	0.85	11.020 0	0.380 0	0.478 2	0.007 9	0.167 7	0.006 6	2 524	34	2 518	35	2 527	33	100
21ZT20-1-39	104.20	102.90	151.90	0.68	11.290 0	0.350 0	0.484 8	0.007 0	0.167 5	0.006 1	2 545	29	2 547	30	2 526	23	100
21ZT20-1-80	359.70	549.00	526.00	1.04	10.530 0	0.350 0	0.458 3	0.009 4	0.167 2	0.005 9	2 478	31	2 429	42	2 526	17	98
21ZT20-1-61	35.10	40.70	49.70	0.82	11.310 0	0.450 0	0.488 3	0.008 7	0.168 0	0.007 2	2 548	35	2 562	38	2 525	45	99
21ZT20-1-126	107.50	160.70	157.60	1.02	9.940 0	0.510 0	0.438 0	0.016 0	0.167 2	0.007 0	2 423	50	2 338	72	2 525	40	96
21ZT20-1-10	146.90	138.70	212.10	0.65	11.290 0	0.380 0	0.493 5	0.008 9	0.167 0	0.006 3	2 545	31	2 584	38	2 523	26	98
21ZT20-1-75	124.60	117.30	181.70	0.65	11.170 0	0.390 0	0.486 2	0.010 0	0.166 7	0.006 3	2 536	32	2 553	44	2 522	27	99
21ZT20-1-34	29.60	18.80	43.90	0.43	11.410 0	0.530 0	0.494 3	0.010 0	0.168 6	0.008 2	2 547	43	2 587	45	2 521	60	98
21ZT20-1-57	205.40	343.00	266.00	1.29	10.620 0	0.340 0	0.457 2	0.007 0	0.166 4	0.006 2	2 488	30	2 426	31	2 521	28	97
21ZT20-1-113	182.40	197.20	285.70	0.69	8.140 0	0.330 0	0.358 0	0.010 0	0.166 7	0.006 8	2 244	36	1 970	50	2 521	38	87

续表 1-1
Continued Table 1-1

样品号	$w_B/10^{-6}$			Th/U	同位素比值				年龄/Ma				谐和度/%
	Total Pb	^{232}Th	^{238}U		$^{207}\text{Pb}/^{235}\text{U}$	2σ	$^{206}\text{Pb}/^{238}\text{U}$	2σ	$^{207}\text{Pb}/^{206}\text{Pb}$	2σ	$^{207}\text{Pb}/^{235}\text{U}$	2σ	
21ZT20-1-11	206.00	363.00	262.80	1.38	10.760 0	0.350 0	0.468 5	0.007 7	0.166 9	0.006 4	2.500	30	99
21ZT20-1-14	138.90	260.10	215.70	1.21	10.570 0	0.350 0	0.463 2	0.008 1	0.166 5	0.006 2	2.482	31	99
21ZT20-1-106	132.40	203.00	179.60	1.13	10.930 0	0.380 0	0.479 2	0.007 7	0.166 8	0.006 6	2.515	32	100
21ZT20-1-31	119.80	117.10	176.10	0.66	10.970 0	0.370 0	0.482 4	0.009 2	0.166 7	0.006 4	2.518	31	99
21ZT20-1-45	58.20	67.80	80.20	0.85	11.070 0	0.390 0	0.476 9	0.008 7	0.167 1	0.006 8	2.529	35	99
21ZT20-1-1	103.20	128.40	140.20	0.92	10.870 0	0.390 0	0.474 7	0.009 7	0.166 9	0.006 6	2.507	34	100
21ZT20-1-84	248.20	981.00	401.50	2.44	8.780 0	0.330 0	0.381 0	0.011 0	0.165 7	0.006 8	2.312	34	89
21ZT20-1-22	134.80	161.90	229.50	0.71	10.320 0	0.360 0	0.458 7	0.006 7	0.166 4	0.006 5	2.462	32	99
21ZT20-1-63	80.10	105.50	122.00	0.86	10.880 0	0.390 0	0.475 2	0.007 1	0.166 7	0.006 8	2.509	34	100
21ZT20-1-99	101.70	102.00	161.50	0.63	10.180 0	0.340 0	0.434 5	0.008 0	0.166 6	0.006 4	2.449	31	95
21ZT20-1-47	161.30	166.00	244.70	0.68	9.540 0	0.530 0	0.410 0	0.018 0	0.166 2	0.006 2	2.377	53	93
21ZT20-1-13	50.20	39.20	79.20	0.49	10.800 0	0.370 0	0.474 0	0.007 1	0.166 8	0.006 5	2.501	32	100
21ZT20-1-29	135.50	142.70	196.20	0.73	10.880 0	0.370 0	0.478 4	0.008 9	0.166 3	0.006 2	2.509	32	100
21ZT20-1-46	140.90	229.00	285.00	0.80	9.020 0	0.400 0	0.386 0	0.013 0	0.166 3	0.006 2	2.328	42	90
21ZT20-1-98	194.50	173.80	276.40	0.63	11.080 0	0.350 0	0.479 6	0.007 4	0.166 2	0.006 2	2.528	29	100
21ZT20-1-108	95.70	137.80	158.00	0.87	8.440 0	0.320 0	0.368 2	0.008 1	0.166 5	0.007 0	2.276	35	88
21ZT20-1-111	89.20	109.30	125.50	0.87	11.040 0	0.410 0	0.487 1	0.010 0	0.166 3	0.007 1	2.524	35	99
21ZT20-1-116	101.70	103.10	148.80	0.69	10.440 0	0.440 0	0.462 0	0.012 0	0.166 1	0.007 0	2.472	39	99
21ZT20-1-8	84.20	88.00	136.20	0.65	10.780 0	0.420 0	0.481 0	0.012 0	0.166 4	0.007 1	2.501	37	99
21ZT20-1-26	53.20	46.80	80.90	0.58	10.930 0	0.440 0	0.473 1	0.010 0	0.167 1	0.007 4	2.510	38	99
21ZT20-1-27	139.30	186.00	201.40	0.92	10.900 0	0.340 0	0.473 7	0.006 6	0.166 3	0.006 1	2.512	29	99
21ZT20-1-49	98.10	214.00	153.00	1.40	9.850 0	0.400 0	0.419 0	0.011 0	0.166 5	0.006 3	2.410	38	93
21ZT20-1-96	276.80	524.00	410.50	1.28	9.580 0	0.330 0	0.415 2	0.008 4	0.165 8	0.006 1	2.390	33	93
21ZT20-1-6	29.80	30.20	44.80	0.67	11.380 0	0.430 0	0.503 8	0.008 2	0.165 7	0.006 9	2.555	33	97
21ZT20-1-25	66.80	51.30	103.50	0.50	11.010 0	0.360 0	0.482 5	0.006 6	0.166 4	0.006 4	2.520	31	99
21ZT20-1-41	75.10	69.60	110.30	0.63	10.980 0	0.430 0	0.477 0	0.011 0	0.166 1	0.006 8	2.518	37	100
21ZT20-1-105	139.60	188.00	219.80	0.86	9.290 0	0.300 0	0.398 9	0.007 9	0.166 0	0.006 3	2.365	30	91
21ZT20-1-35	94.80	107.50	135.80	0.79	11.150 0	0.380 0	0.488 4	0.007 5	0.166 0	0.006 4	2.532	31	99
21ZT20-1-94	61.60	71.40	86.40	0.83	10.020 0	0.410 0	0.434 0	0.011 0	0.166 4	0.006 4	2.425	39	96
21ZT20-1-121	25.40	18.20	38.80	0.47	11.470 0	0.510 0	0.496 6	0.011 0	0.167 3	0.008 1	2.554	41	98
21ZT20-1-17	193.90	189.20	339.40	0.56	10.090 0	0.440 0	0.439 0	0.013 0	0.165 9	0.006 4	2.433	41	96
21ZT20-1-28	100.50	135.50	143.90	0.94	10.920 0	0.350 0	0.477 4	0.007 2	0.166 0	0.006 2	2.512	30	100
21ZT20-1-56	117.50	141.80	176.20	0.80	10.700 0	0.420 0	0.451 9	0.009 7	0.165 8	0.006 9	2.495	36	96

续表 1-2
Continued Table 1-2

样品号	$w_B/10^{-6}$			Th/U	同位素比值				年龄/Ma				谐和度/%				
	Total Pb	^{232}Th	^{238}U		$^{207}\text{Pb}/^{235}\text{U}$	2σ	$^{206}\text{Pb}/^{238}\text{U}$	2σ	$^{207}\text{Pb}/^{206}\text{Pb}$	2σ							
21ZT20-1-71	67.20	65.50	106.20	0.62	10.490 0	0.370 0	0.460 9	0.008 1	0.165 2	0.006 9	2.481	35	2.443	36	2.510	44	98
21ZT20-1-107	91.90	107.90	134.60	0.80	10.810 0	0.430 0	0.478 0	0.011 0	0.165 8	0.006 6	2.504	36	2.515	47	2.510	36	100
21ZT20-1-42	121.90	133.70	184.90	0.72	10.730 0	0.340 0	0.459 9	0.007 7	0.165 4	0.006 1	2.496	30	2.437	34	2.509	24	98
21ZT20-1-55	119.10	103.30	171.90	0.60	11.1600	0.370 0	0.480 2	0.006 8	0.165 6	0.006 1	2.533	31	2.527	30	2.509	23	100
21ZT20-1-91	216.50	200.00	303.20	0.66	9.690 0	0.420 0	0.430 0	0.014 0	0.165 6	0.006 7	2.401	40	2.301	65	2.509	37	96
21ZT20-1-97	118.40	131.50	192.90	0.68	10.890 0	0.370 0	0.475 9	0.008 5	0.165 8	0.006 4	2.515	30	2.508	37	2.509	31	100
21ZT20-1-109	163.00	205.00	251.50	0.82	9.920 0	0.490 0	0.430 0	0.017 0	0.164 3	0.007 1	2.423	46	2.302	77	2.509	39	95
21ZT20-1-93	85.30	134.20	115.40	1.16	10.760 0	0.370 0	0.473 8	0.008 0	0.165 9	0.006 7	2.500	32	2.499	35	2.508	36	100
21ZT20-1-104	77.00	66.30	116.10	0.57	10.860 0	0.410 0	0.476 9	0.009 0	0.165 7	0.006 7	2.507	36	2.520	36	2.508	35	99
21ZT20-1-85	44.80	64.50	58.80	1.10	11.600 0	0.400 0	0.500 3	0.008 0	0.166 2	0.006 6	2.567	32	2.613	34	2.507	34	98
21ZT20-1-7	124.50	159.30	179.90	0.89	10.790 0	0.330 0	0.476 8	0.006 2	0.165 4	0.006 1	2.504	29	2.512	27	2.506	22	100
21ZT20-1-50	113.40	182.50	154.00	1.19	11.010 0	0.400 0	0.477 4	0.009 9	0.165 5	0.006 8	2.527	31	2.514	43	2.506	38	99
21ZT20-1-51	88.00	79.10	130.80	0.60	10.840 0	0.360 0	0.467 4	0.007 5	0.165 7	0.006 6	2.506	31	2.471	33	2.506	34	99
21ZT20-1-87	125.90	181.00	200.10	0.90	10.540 0	0.370 0	0.463 4	0.009 6	0.165 4	0.006 8	2.481	33	2.454	42	2.506	40	99
21ZT20-1-103	117.90	162.00	162.40	1.00	10.470 0	0.360 0	0.460 2	0.008 2	0.165 6	0.006 4	2.473	32	2.439	36	2.506	30	99
21ZT20-1-128	246.80	110.40	423.00	0.26	10.730 0	0.360 0	0.468 0	0.011 0	0.165 4	0.006 3	2.497	31	2.474	47	2.506	29	99
21ZT20-1-66	66.20	97.70	94.10	1.04	10.860 0	0.390 0	0.473 6	0.008 2	0.165 4	0.006 9	2.506	33	2.498	36	2.505	43	100
21ZT20-1-68	44.00	38.20	64.60	0.59	11.260 0	0.460 0	0.486 0	0.011 0	0.166 0	0.007 3	2.539	38	2.549	49	2.505	47	100
21ZT20-1-70	78.10	101.90	112.70	0.90	10.650 0	0.370 0	0.474 5	0.008 6	0.165 4	0.006 4	2.490	33	2.502	37	2.505	31	100
21ZT20-1-92	198.70	246.80	344.90	0.72	9.140 0	0.340 0	0.403 0	0.011 0	0.165 1	0.006 1	2.349	35	2.189	45	2.505	25	93
21ZT20-1-30	120.20	238.20	237.80	1.00	7.990 0	0.300 0	0.355 7	0.007 3	0.165 2	0.006 9	2.228	33	1.961	35	2.504	40	87
21ZT20-1-40	215.70	419.00	342.00	1.23	9.490 0	0.330 0	0.410 3	0.010 0	0.165 1	0.005 9	2.381	32	2.212	46	2.503	20	93
21ZT20-1-119	209.50	478.00	437.00	1.09	8.590 0	0.380 0	0.368 0	0.011 0	0.165 1	0.006 6	2.289	40	2.017	52	2.503	35	87
21ZT20-1-52	83.00	120.90	113.40	1.07	11.000 0	0.370 0	0.473 9	0.007 5	0.165 3	0.006 4	2.520	31	2.499	33	2.502	32	99
21ZT20-1-54	177.90	283.00	285.20	0.99	9.640 0	0.320 0	0.415 2	0.007 5	0.164 8	0.006 1	2.396	31	2.237	34	2.502	23	93
21ZT20-1-76	122.10	55.70	232.00	0.24	10.620 0	0.540 0	0.475 0	0.012 0	0.164 9	0.007 8	2.488	47	2.504	51	2.502	56	99
21ZT20-1-32	82.20	208.00	100.60	2.07	10.890 0	0.430 0	0.483 5	0.010 0	0.164 9	0.006 6	2.510	37	2.541	44	2.501	36	99
21ZT20-1-48	58.90	72.20	88.60	0.81	10.430 0	0.400 0	0.437 1	0.007 6	0.165 6	0.007 1	2.468	36	2.342	36	2.501	44	95
21ZT20-1-64	145.60	263.00	216.40	1.22	10.460 0	0.360 0	0.457 4	0.008 2	0.164 7	0.006 1	2.473	31	2.425	36	2.501	24	98
21ZT20-1-73	190.90	390.00	285.00	1.37	9.160 0	0.330 0	0.408 8	0.007 3	0.165 0	0.006 4	2.350	33	2.208	34	2.501	32	94
21ZT20-1-78	135.50	201.20	197.30	1.02	10.880 0	0.450 0	0.485 3	0.009 5	0.164 9	0.007 0	2.510	38	2.549	41	2.501	43	98
21ZT20-1-112	146.00	251.40	194.30	1.29	10.720 0	0.480 0	0.463 0	0.012 0	0.165 2	0.007 5	2.494	42	2.449	53	2.501	51	98
21ZT20-1-115	241.80	583.00	389.50	1.50	9.200 0	0.350 0	0.409 5	0.010 0	0.164 8	0.006 2	2.354	36	2.211	47	2.501	27	94

续表 1-3
Continued Table 1-3

样品号	$w_B/10^{-6}$		Th/U	同位素比值				年龄/Ma				谐和度/%					
	Total Pb	^{232}Th		$^{207}\text{Pb}/^{235}\text{U}$	$^{206}\text{Pb}/^{238}\text{U}$	$^{207}\text{Pb}/^{206}\text{Pb}$	$^{206}\text{Pb}/^{238}\text{U}$	$^{207}\text{Pb}/^{235}\text{U}$	$^{206}\text{Pb}/^{238}\text{U}$	$^{207}\text{Pb}/^{206}\text{Pb}$							
21ZT20-1-16	173.90	169.50	340.00	0.50	9.280 0	0.310 0	0.414 0	0.009 5	0.164 7	0.006 1	2 364	32	2 231	43	2 500	25	94
21ZT20-1-44	111.90	190.20	151.20	1.26	10.770 0	0.380 0	0.468 3	0.007 1	0.164 9	0.006 4	2 500	33	2 475	31	2 500	32	99
21ZT20-1-120	65.90	60.50	116.20	0.52	10.760 0	0.370 0	0.473 5	0.009 0	0.164 7	0.006 2	2 500	34	2 496	40	2 500	28	100
21ZT20-1-53	75.40	113.20	95.60	1.18	11.130 0	0.390 0	0.477 7	0.007 6	0.164 7	0.006 2	2 528	32	2 515	33	2 499	28	99
21ZT20-1-37	163.90	312.00	265.00	1.18	8.150 0	0.420 0	0.351 0	0.014 0	0.164 9	0.006 6	2 233	47	1 935	68	2 498	35	86
21ZT20-1-114	138.20	145.70	202.30	0.72	10.930 0	0.340 0	0.485 2	0.007 4	0.163 8	0.006 0	2 515	29	2 549	32	2 498	25	99
21ZT20-1-127	147.30	255.00	232.00	1.10	9.830 0	0.340 0	0.430 0	0.008 1	0.164 5	0.006 3	2 416	32	2 305	37	2 498	29	95
21ZT20-1-20	109.20	114.50	149.50	0.77	10.810 0	0.420 0	0.480 0	0.015 0	0.164 6	0.006 5	2 506	38	2 524	64	2 496	35	99
21ZT20-1-86	266.00	618.00	406.50	1.52	9.170 0	0.290 0	0.403 5	0.006 1	0.164 4	0.005 9	2 351	29	2 184	28	2 496	20	93
21ZT20-1-15	172.50	213.70	319.70	0.67	9.690 0	0.330 0	0.431 6	0.008 5	0.164 2	0.006 3	2 404	31	2 312	38	2 495	30	96
21ZT20-1-79	68.90	114.60	89.80	1.28	11.190 0	0.370 0	0.494 0	0.006 7	0.164 8	0.006 3	2 535	31	2 587	29	2 495	31	98
21ZT20-1-69	194.60	488.00	369.70	1.32	8.090 0	0.280 0	0.355 8	0.007 4	0.163 6	0.006 3	2 240	30	1 961	35	2 492	32	87
21ZT20-1-62	96.20	222.00	113.10	1.96	10.830 0	0.390 0	0.472 9	0.009 2	0.163 8	0.006 6	2 506	34	2 495	40	2 489	36	100
21ZT20-1-4	133.60	226.00	199.00	1.14	10.970 0	0.420 0	0.481 5	0.009 7	0.163 7	0.006 7	2 517	36	2 533	42	2 488	38	99
21ZT20-1-67	193.70	326.00	341.30	0.96	9.530 0	0.330 0	0.419 5	0.008 1	0.163 5	0.006 3	2 388	33	2 257	37	2 487	31	94
21ZT20-1-122	35.00	26.10	55.20	0.47	10.800 0	0.410 0	0.481 1	0.008 5	0.164 4	0.007 0	2 499	36	2 530	37	2 486	42	99
21ZT20-1-60	276.60	372.60	516.20	0.72	9.060 0	0.330 0	0.398 3	0.009 5	0.163 1	0.007 0	2 342	34	2 160	44	2 484	44	92
21ZT20-1-100	151.50	186.10	262.10	0.71	8.860 0	0.330 0	0.386 7	0.008 8	0.162 8	0.006 4	2 319	34	2 106	41	2 484	36	90
21ZT20-1-18	137.10	121.30	258.20	0.47	9.620 0	0.350 0	0.437 4	0.010 0	0.163 1	0.006 4	2 402	30	2 337	45	2 483	33	97
21ZT20-1-24	188.20	293.60	310.40	0.95	10.410 0	0.430 0	0.460 0	0.013 0	0.163 0	0.006 4	2 468	39	2 437	58	2 483	32	99
21ZT20-1-43	174.00	305.50	321.10	0.95	8.200 0	0.300 0	0.352 9	0.008 6	0.163 0	0.006 1	2 249	33	1 946	41	2 481	27	86
21ZT20-1-65	181.10	326.00	361.00	0.90	8.220 0	0.390 0	0.367 3	0.010 0	0.161 9	0.007 4	2 265	35	2 016	48	2 470	53	88
21ZT20-1-72	207.40	299.20	563.00	0.53	7.680 0	0.320 0	0.336 0	0.010 0	0.162 1	0.007 6	2 191	38	1 865	50	2 469	54	84
21ZT20-1-101	245.50	538.00	526.00	1.02	6.550 0	0.300 0	0.285 4	0.007 9	0.160 2	0.007 1	2 049	40	1 618	40	2 452	48	76
21ZT20-1-74	198.10	286.00	474.00	0.60	6.760 0	0.490 0	0.314 0	0.018 0	0.159 0	0.010 0	2 075	65	1 756	86	2 434	97	83
变质型碎屑锆石																	
21ZT20-1-23	90.30	82.50	141.40	0.58	10.840 0	0.370 0	0.469 4	0.007 5	0.167 2	0.007 0	2 506	31	2 480	33	2 519	40	99
21ZT20-1-81	38.30	28.70	59.60	0.48	10.490 0	0.490 0	0.460 3	0.008 4	0.168 2	0.009 1	2 476	43	2 440	37	2 531	69	99

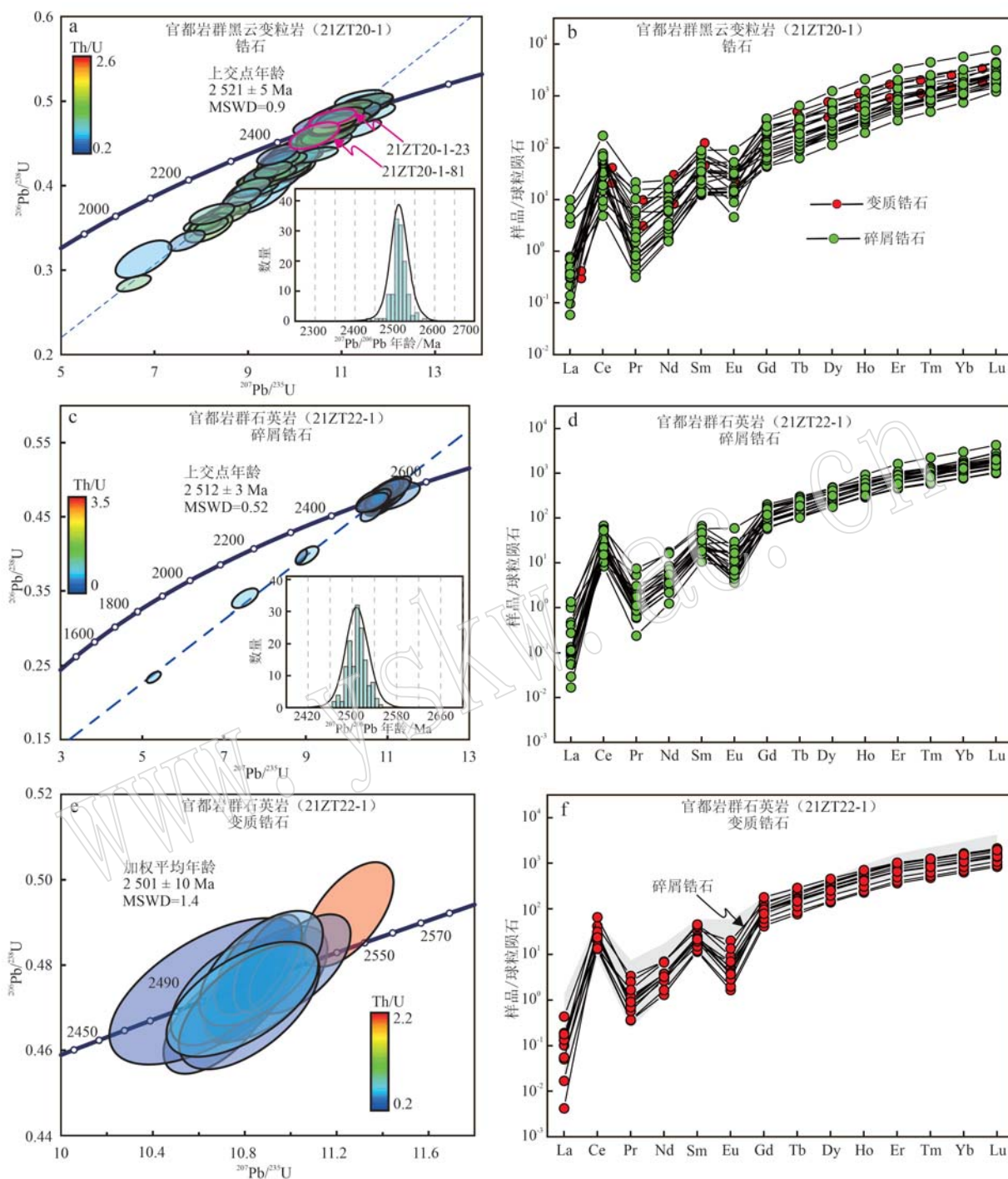


图8 赞皇杂岩官都岩群黑云变粒岩与石英岩中锆石 U-Pb 谐和图(a, c, e)与稀土元素配分模式图(b, d, f; 标准化数据据 McDonough and Sun, 1995)

Fig. 8 Concordia diagrams (a, c, e) and CI-normalized rare earth element patterns (b, d, f; chondrite data after McDonough and Sun, 1995) of zircons from the biotite leptynite and quartzite in Guandu Group of the Zhanhuang Complex

显示重稀土元素明显上翘, 相应的 Lu_N/Sm_N 值为 33.47~52.55; 2 个变质锆石具有正 Ce 异常与负 Eu 异常的特征, Ce/Ce^* 值为 8.98~13.21; Eu/Eu^* 值为 0.17~0.19(表 3)。

石英岩中 148 个碎屑锆石具有变化相对较大的稀土元素总量, 介于 $99.3 \times 10^{-6} \sim 2137.59 \times 10^{-6}$ 之间(图 8d, 表 4)。从球粒陨石标准化稀土元素配分曲线特征可以明显看出, 148 个碎屑锆石具有轻

表2 赞皇杂岩官都群石英锆石 LA-ICP-MS U-Pb 测试结果
Table 2 LA-ICP-MS zircon U-Pb dating results of quartzites of the Guandu Group in the Zanhuan Complex

样品号	$w_B/10^{-6}$			Th/U	同位素比值				年龄/Ma				谐和度/%				
	Total Pb	^{232}Th	^{238}U		$^{206}\text{Pb}/^{238}\text{U}$		$^{207}\text{Pb}/^{235}\text{U}$		$^{206}\text{Pb}/^{238}\text{U}$		$^{207}\text{Pb}/^{235}\text{U}$						
					2σ	2σ	2σ	2σ	2σ	2σ	2σ	2σ					
碎屑锆石																	
21ZT22-1-130	100.70	79.20	150.00	0.53	13.030 0	0.220 0	0.513 8	0.011 0	0.183 0	0.002 2	2 680	16	2 672	48	2 677	20	100
21ZT22-1-30	35.40	48.20	46.10	1.05	13.400 0	0.270 0	0.532 3	0.011 0	0.183 2	0.003 4	2 702	20	2 753	48	2 671	32	98
21ZT22-1-61	64.40	43.90	106.30	0.41	11.090 0	0.200 0	0.479 0	0.009 7	0.169 9	0.003 0	2 529	17	2 522	42	2 552	29	100
21ZT22-1-42	28.90	19.90	47.20	0.42	11.200 0	0.240 0	0.485 4	0.011 0	0.169 6	0.003 1	2 536	20	2 549	47	2 546	30	99
21ZT22-1-56	45.40	39.80	69.80	0.57	11.040 0	0.230 0	0.480 6	0.010 0	0.169 0	0.003 3	2 523	19	2 529	45	2 545	32	100
21ZT22-1-76	38.30	30.20	64.30	0.47	10.830 0	0.320 0	0.468 0	0.013 0	0.169 3	0.005 7	2 506	28	2 475	59	2 542	57	99
21ZT22-1-41	75.80	59.50	126.40	0.47	10.950 0	0.190 0	0.472 1	0.011 0	0.168 1	0.002 8	2 517	16	2 492	46	2 539	29	99
21ZT22-1-145	53.70	48.20	84.20	0.57	11.190 0	0.490 0	0.478 0	0.015 0	0.168 8	0.007 0	2 535	42	2 518	64	2 538	70	99
21ZT22-1-53	54.30	45.60	84.50	0.54	10.950 0	0.160 0	0.476 2	0.009 2	0.168 1	0.002 2	2 517	14	2 512	41	2 536	22	100
21ZT22-1-38	150.70	187.00	221.80	0.84	11.060 0	0.170 0	0.484 0	0.010 0	0.168 2	0.002 4	2 527	14	2 544	45	2 536	24	99
21ZT22-1-46	56.70	40.60	93.40	0.44	10.960 0	0.160 0	0.477 6	0.009 2	0.168 3	0.002 1	2 517	14	2 516	40	2 535	21	100
21ZT22-1-43	154.50	188.70	223.60	0.84	10.930 0	0.160 0	0.479 7	0.011 0	0.168 0	0.002 1	2 519	15	2 525	48	2 535	21	100
21ZT22-1-78	37.70	24.90	62.70	0.40	10.970 0	0.190 0	0.476 4	0.009 8	0.168 4	0.003 2	2 518	16	2 511	43	2 534	32	100
21ZT22-1-28	109.50	117.40	184.00	0.64	10.940 0	0.110 0	0.477 7	0.009 5	0.168 0	0.002 0	2 519	10	2 516	41	2 534	20	100
21ZT22-1-58	128.70	83.10	213.20	0.39	10.990 0	0.120 0	0.479 4	0.009 1	0.167 9	0.001 7	2 521	10	2 524	39	2 533	18	100
21ZT22-1-51	69.80	54.20	112.90	0.48	10.930 0	0.170 0	0.478 9	0.009 4	0.167 9	0.003 0	2 515	14	2 522	41	2 530	29	100
21ZT22-1-50	30.20	27.50	47.20	0.58	11.050 0	0.260 0	0.482 1	0.011 0	0.168 4	0.004 1	2 523	21	2 535	46	2 530	40	100
21ZT22-1-106	63.40	51.10	110.90	0.46	11.020 0	0.190 0	0.477 0	0.009 7	0.167 7	0.002 5	2 523	16	2 514	42	2 530	26	100
21ZT22-1-72	49.70	38.80	77.10	0.50	10.980 0	0.180 0	0.480 5	0.010 0	0.167 8	0.003 0	2 520	15	2 528	45	2 529	30	100
21ZT22-1-71	135.30	156.80	201.50	0.78	10.950 0	0.250 0	0.481 0	0.014 0	0.167 1	0.002 8	2 518	21	2 533	60	2 527	27	99
21ZT22-1-20	44.80	47.70	70.00	0.68	11.020 0	0.170 0	0.477 6	0.009 4	0.167 8	0.002 7	2 522	14	2 516	41	2 527	27	100
21ZT22-1-48	53.70	57.50	87.10	0.66	10.920 0	0.140 0	0.477 1	0.009 8	0.167 3	0.002 1	2 515	12	2 513	43	2 526	21	100
21ZT22-1-59	139.60	349.60	167.50	2.09	10.890 0	0.160 0	0.478 2	0.009 7	0.167 1	0.002 1	2 512	13	2 518	42	2 525	21	100
21ZT22-1-73	106.60	70.60	172.10	0.41	10.900 0	0.140 0	0.477 9	0.009 3	0.166 9	0.001 8	2 513	12	2 518	41	2 524	19	100
21ZT22-1-68	109.60	85.10	169.30	0.50	11.070 0	0.230 0	0.485 0	0.012 0	0.167 0	0.003 2	2 528	20	2 548	51	2 524	32	99
21ZT22-1-32	46.50	42.70	73.70	0.58	10.980 0	0.190 0	0.481 5	0.009 8	0.166 9	0.002 5	2 518	16	2 533	42	2 524	27	99
21ZT22-1-133	20.50	24.60	31.40	0.78	11.020 0	0.240 0	0.476 0	0.009 9	0.167 6	0.003 7	2 522	20	2 508	43	2 524	36	99
21ZT22-1-127	80.20	63.50	129.20	0.49	10.990 0	0.160 0	0.477 5	0.010 0	0.167 1	0.002 5	2 520	14	2 515	44	2 524	25	100
21ZT22-1-70	131.20	82.90	219.40	0.38	10.890 0	0.120 0	0.476 7	0.009 0	0.166 6	0.001 6	2 514	10	2 512	39	2 523	16	100
21ZT22-1-60	58.40	58.90	97.90	0.60	10.910 0	0.320 0	0.478 8	0.013 0	0.167 2	0.004 4	2 513	27	2 521	55	2 523	45	100
21ZT22-1-57	75.70	72.40	116.70	0.62	10.950 0	0.150 0	0.479 4	0.009 0	0.167 0	0.002 0	2 517	12	2 524	39	2 523	20	100
21ZT22-1-16	126.40	166.80	198.00	0.84	10.970 0	0.200 0	0.477 5	0.011 0	0.166 8	0.002 4	2 522	16	2 515	48	2 522	24	100

续表 2-1
Continued Table 2-1

样品号	$w_B/10^{-6}$			Th/U	同位素比值						年龄/Ma						谐和度/%						
	Total Pb	^{232}Th	^{238}U		$^{207}\text{Pb}/^{235}\text{U}$			$^{206}\text{Pb}/^{238}\text{U}$			$^{207}\text{Pb}/^{206}\text{Pb}$			$^{207}\text{Pb}/^{235}\text{U}$				$^{206}\text{Pb}/^{238}\text{U}$			$^{207}\text{Pb}/^{206}\text{Pb}$		
					2σ	2σ	2σ	2σ	2σ	2σ	2σ	2σ	2σ	2σ	2σ	2σ		2σ	2σ	2σ	2σ	2σ	2σ
21ZT22-1-82	264.90	319.20	400.10	0.80	10.950 0	0.180 0	0.479 9	0.010 0	0.166 7	0.002 1	2 517	15	2 526	45	2 521	21	100						
21ZT22-1-54	51.60	46.60	81.90	0.57	10.880 0	0.150 0	0.478 1	0.009 3	0.166 6	0.002 1	2 511	13	2 518	41	2 521	20	100						
21ZT22-1-123	122.10	113.00	192.30	0.59	10.990 0	0.150 0	0.478 9	0.009 9	0.166 7	0.002 3	2 521	12	2 521	43	2 521	23	100						
21ZT22-1-39	40.90	30.50	69.00	0.44	10.730 0	0.200 0	0.472 8	0.010 0	0.167 0	0.003 2	2 496	18	2 495	44	2 520	33	100						
21ZT22-1-150	156.10	149.60	240.40	0.62	11.000 0	0.180 0	0.481 0	0.010 0	0.166 5	0.002 1	2 521	15	2 531	44	2 519	21	100						
21ZT22-1-93	23.40	14.80	38.60	0.38	10.970 0	0.380 0	0.477 9	0.012 0	0.166 4	0.005 0	2 514	31	2 516	54	2 518	53	100						
21ZT22-1-65	96.70	99.40	141.80	0.70	10.900 0	0.160 0	0.477 9	0.009 5	0.166 6	0.002 1	2 512	13	2 517	41	2 518	21	100						
21ZT22-1-34	52.90	46.70	89.50	0.52	10.880 0	0.260 0	0.477 6	0.011 0	0.166 7	0.003 3	2 509	22	2 516	47	2 518	34	100						
21ZT22-1-33	68.10	36.20	115.50	0.31	10.870 0	0.160 0	0.476 4	0.009 2	0.166 6	0.002 4	2 510	13	2 511	40	2 518	24	100						
21ZT22-1-114	124.70	137.50	190.10	0.72	10.970 0	0.200 0	0.477 3	0.012 0	0.166 4	0.003 2	2 519	17	2 514	52	2 518	32	100						
21ZT22-1-95	72.10	47.50	128.60	0.37	10.770 0	0.250 0	0.467 6	0.012 0	0.166 7	0.004 3	2 501	22	2 472	52	2 517	44	99						
21ZT22-1-90	57.70	45.00	95.20	0.47	10.940 0	0.170 0	0.475 9	0.009 2	0.166 5	0.002 3	2 515	14	2 508	40	2 517	23	100						
21ZT22-1-86	42.50	27.90	72.10	0.39	10.900 0	0.350 0	0.471 4	0.011 0	0.166 7	0.005 3	2 511	30	2 489	49	2 517	54	99						
21ZT22-1-74	84.20	97.20	140.90	0.69	10.780 0	0.160 0	0.473 7	0.009 3	0.166 3	0.002 1	2 503	14	2 499	41	2 517	21	100						
21ZT22-1-52	63.80	65.10	102.30	0.64	10.950 0	0.190 0	0.480 9	0.009 6	0.166 4	0.002 3	2 515	16	2 530	42	2 516	23	99						
21ZT22-1-36	30.60	21.00	50.20	0.42	10.800 0	0.260 0	0.480 2	0.011 0	0.163 7	0.003 9	2 502	23	2 527	46	2 516	19	99						
21ZT22-1-29	54.80	29.80	92.80	0.32	10.910 0	0.200 0	0.479 2	0.009 6	0.166 1	0.002 9	2 512	17	2 523	42	2 516	31	100						
21ZT22-1-5	51.70	64.00	76.50	0.84	10.990 0	0.330 0	0.479 4	0.012 0	0.166 3	0.004 7	2 520	29	2 524	53	2 515	48	100						
21ZT22-1-128	49.60	45.00	76.90	0.59	10.990 0	0.260 0	0.478 3	0.011 0	0.166 2	0.003 2	2 520	22	2 519	48	2 515	32	100						
21ZT22-1-89	125.80	133.90	200.40	0.67	11.070 0	0.260 0	0.484 6	0.012 0	0.166 0	0.003 2	2 528	22	2 546	54	2 514	31	99						
21ZT22-1-40	110.30	83.10	179.30	0.46	10.910 0	0.130 0	0.480 4	0.009 0	0.166 0	0.001 9	2 514	11	2 528	39	2 514	19	99						
21ZT22-1-25	57.70	61.40	87.50	0.70	10.990 0	0.330 0	0.485 0	0.013 0	0.166 2	0.004 2	2 520	28	2 548	55	2 514	43	99						
21ZT22-1-96	37.70	28.60	63.80	0.45	10.800 0	0.300 0	0.474 0	0.013 0	0.165 2	0.004 3	2 503	26	2 497	56	2 513	46	100						
21ZT22-1-88	54.10	38.90	90.40	0.43	10.850 0	0.200 0	0.472 7	0.010 0	0.166 2	0.003 0	2 508	17	2 494	45	2 513	30	99						
21ZT22-1-8	67.50	66.90	112.60	0.59	10.770 0	0.220 0	0.467 1	0.009 7	0.166 4	0.003 0	2 502	19	2 470	42	2 513	30	99						
21ZT22-1-47	52.40	38.30	85.60	0.45	10.940 0	0.180 0	0.480 3	0.009 7	0.166 3	0.002 5	2 514	16	2 527	42	2 513	26	99						
21ZT22-1-35	87.10	96.90	143.40	0.68	10.930 0	0.170 0	0.482 3	0.009 4	0.166 0	0.002 3	2 515	14	2 537	41	2 513	23	99						
21ZT22-1-160	14.80	15.20	24.20	0.63	10.910 0	0.400 0	0.475 0	0.013 0	0.167 1	0.005 6	2 508	34	2 502	56	2 513	55	100						
21ZT22-1-134	40.00	41.60	63.30	0.66	11.000 0	0.190 0	0.478 7	0.009 6	0.166 3	0.002 5	2 519	17	2 520	42	2 513	26	100						
21ZT22-1-44	116.80	76.80	195.30	0.39	10.740 0	0.240 0	0.473 7	0.013 0	0.165 8	0.001 8	2 495	20	2 495	55	2 512	18	100						
21ZT22-1-31	90.80	86.30	144.00	0.60	10.850 0	0.150 0	0.478 2	0.009 5	0.165 9	0.002 3	2 508	13	2 519	41	2 512	23	100						
21ZT22-1-24	50.60	41.00	81.80	0.50	10.810 0	0.240 0	0.475 6	0.010 0	0.166 2	0.003 7	2 508	19	2 507	45	2 512	38	100						
21ZT22-1-159	106.70	122.00	161.40	0.76	10.880 0	0.160 0	0.476 6	0.009 8	0.165 9	0.002 4	2 512	14	2 512	43	2 512	24	100						

续表 2-2
Continued Table 2-2

样品号	$w_B/10^{-6}$		Th/U	同位素比值				年龄/Ma				谐和度/%			
	Total Pb	^{232}Th		^{238}U	$^{207}\text{Pb}/^{235}\text{U}$	2σ	$^{206}\text{Pb}/^{238}\text{U}$	2σ	$^{207}\text{Pb}/^{206}\text{Pb}$	2σ					
21ZT22-1-144	89.30	67.90	137.80	0.49	10.970 0	0.260 0	0.479 0	0.011 0	0.166 1	0.003 8	2.518	2.512	50	39	100
21ZT22-1-138	82.70	10.30	155.90	0.07	10.940 0	0.150 0	0.478 9	0.009 6	0.165 8	0.002 1	2.517	2.522	42	22	100
21ZT22-1-129	92.40	97.60	143.70	0.68	10.920 0	0.180 0	0.476 4	0.009 7	0.165 9	0.002 3	2.513	2.511	42	24	100
21ZT22-1-121	64.80	52.40	107.60	0.49	10.790 0	0.200 0	0.472 9	0.011 0	0.165 8	0.002 5	2.504	2.495	47	25	100
21ZT22-1-99	90.50	99.30	143.00	0.69	10.850 0	0.120 0	0.474 1	0.009 5	0.165 7	0.001 8	2.509	2.503	40	18	100
21ZT22-1-63	117.00	80.00	193.30	0.41	10.830 0	0.140 0	0.479 4	0.009 2	0.165 4	0.001 9	2.507	2.524	40	21	99
21ZT22-1-27	57.60	51.40	94.30	0.54	10.800 0	0.170 0	0.473 9	0.009 7	0.1656	0.002 7	2.506	2.500	42	29	100
21ZT22-1-64	100.00	74.80	164.90	0.45	10.840 0	0.130 0	0.478 1	0.009 0	0.165 4	0.001 7	2.508	2.518	39	18	100
21ZT22-1-49	47.50	37.50	77.70	0.48	10.800 0	0.170 0	0.476 2	0.009 4	0.166 0	0.002 4	2.503	2.509	41	25	100
21ZT22-1-100	68.10	58.20	115.50	0.50	10.610 0	0.220 0	0.456 9	0.010 0	0.166 0	0.003 9	2.487	2.425	45	39	97
21ZT22-1-97	104.00	79.40	171.80	0.46	10.890 0	0.120 0	0.475 5	0.009 2	0.165 5	0.001 7	2.512	2.507	40	17	100
21ZT22-1-81	22.30	27.20	33.90	0.80	10.990 0	0.300 0	0.484 9	0.011 0	0.166 2	0.003 9	2.521	2.547	49	39	99
21ZT22-1-17	41.50	29.00	65.90	0.44	11.290 0	0.230 0	0.492 1	0.011 0	0.165 9	0.003 4	2.544	2.579	46	34	99
21ZT22-1-107	59.50	41.90	98.30	0.43	10.920 0	0.140 0	0.477 9	0.009 2	0.165 6	0.002 0	2.516	2.517	40	20	100
21ZT22-1-13	55.50	29.70	93.70	0.32	10.950 0	0.160 0	0.477 5	0.009 1	0.165 6	0.002 3	2.516	2.516	40	23	100
21ZT22-1-87	53.40	43.30	87.60	0.49	10.790 0	0.150 0	0.474 0	0.009 4	0.165 3	0.002 4	2.502	2.500	41	24	100
21ZT22-1-85	37.30	27.30	61.20	0.45	10.960 0	0.170 0	0.480 5	0.009 8	0.165 7	0.002 6	2.517	2.528	43	26	100
21ZT22-1-84	95.90	108.10	156.60	0.69	11.070 0	0.140 0	0.484 7	0.009 5	0.165 4	0.001 9	2.527	2.547	41	19	99
21ZT22-1-55	38.80	23.20	65.60	0.35	10.760 0	0.200 0	0.474 6	0.009 3	0.165 9	0.002 9	2.499	2.503	41	30	100
21ZT22-1-4	55.10	34.50	92.00	0.37	11.010 0	0.160 0	0.478 8	0.009 5	0.165 6	0.002 5	2.522	2.521	41	25	100
21ZT22-1-141	68.10	54.00	112.50	0.48	10.910 0	0.150 0	0.476 2	0.009 5	0.165 4	0.002 0	2.517	2.510	42	20	100
21ZT22-1-126	81.90	88.50	134.20	0.66	10.820 0	0.190 0	0.478 2	0.010 0	0.164 7	0.002 3	2.506	2.519	46	26	99
21ZT22-1-83	115.10	135.30	179.90	0.75	11.110 0	0.220 0	0.490 8	0.011 0	0.165 2	0.002 9	2.531	2.574	49	29	98
21ZT22-1-79	35.50	26.30	58.80	0.45	10.860 0	0.190 0	0.477 3	0.009 7	0.165 8	0.002 8	2.508	2.514	42	28	100
21ZT22-1-75	17.20	13.50	28.70	0.47	10.820 0	0.370 0	0.474 4	0.012 0	0.165 1	0.005 2	2.503	2.501	51	53	100
21ZT22-1-23	155.90	173.60	246.30	0.70	10.800 0	0.190 0	0.474 6	0.009 9	0.165 3	0.002 8	2.504	2.503	43	29	100
21ZT22-1-111	67.70	54.00	109.70	0.49	11.010 0	0.130 0	0.480 6	0.009 2	0.165 4	0.002 2	2.522	2.529	40	22	100
21ZT22-1-108	87.90	96.50	148.30	0.65	10.940 0	0.150 0	0.475 1	0.009 8	0.165 2	0.002 1	2.517	2.510	41	22	100
21ZT22-1-139	73.60	78.70	119.00	0.66	10.750 0	0.210 0	0.470 7	0.011 0	0.165 3	0.003 3	2.499	2.486	47	34	99
21ZT22-1-22	38.80	27.80	64.40	0.43	10.790 0	0.190 0	0.476 6	0.009 6	0.165 2	0.003 2	2.503	2.511	42	32	100
21ZT22-1-21	67.70	60.80	107.90	0.56	10.950 0	0.200 0	0.481 5	0.009 8	0.165 1	0.002 8	2.516	2.533	43	28	99
21ZT22-1-124	72.10	55.70	119.10	0.47	10.880 0	0.140 0	0.475 2	0.009 2	0.165 0	0.001 9	2.511	2.508	41	19	100
21ZT22-1-10	220.90	187.40	371.00	0.51	10.750 0	0.190 0	0.473 2	0.011 0	0.164 8	0.002 3	2.503	2.496	47	23	100

续表 2-3
Continued Table 2-3

样品号	$w_B/10^{-6}$			Th/U	同位素比值						年龄/Ma						谐和度/%
	Total Pb	^{232}Th	^{238}U		$^{207}\text{Pb}/^{235}\text{U}$			$^{206}\text{Pb}/^{238}\text{U}$			$^{207}\text{Pb}/^{206}\text{Pb}$			$^{206}\text{Pb}/^{238}\text{U}$			
					2 σ	2 σ	2 σ	2 σ	2 σ	2 σ	2 σ	2 σ	2 σ	2 σ	2 σ	2 σ	
21ZT22-1-137	52.70	41.70	86.40	0.48	10.910 0	0.170 0	0.476 8	0.009 6	0.165 1	0.002 5	2.513	15	2.512	42	2.501	26	100
21ZT22-1-110	128.60	84.80	212.40	0.40	10.920 0	0.130 0	0.481 2	0.009 6	0.164 6	0.001 7	2.515	11	2.532	41	2.501	17	99
21ZT22-1-102	88.00	62.00	145.70	0.43	10.880 0	0.130 0	0.476 9	0.009 1	0.164 8	0.002 0	2.511	11	2.513	40	2.501	20	100
21ZT22-1-19	38.20	28.80	62.90	0.46	10.860 0	0.180 0	0.477 8	0.009 9	0.165 1	0.002 8	2.507	16	2.516	43	2.500	28	100
21ZT22-1-18	86.80	93.50	136.00	0.69	10.890 0	0.160 0	0.479 5	0.009 2	0.164 8	0.002 2	2.511	13	2.524	40	2.500	23	99
21ZT22-1-115	50.00	35.40	81.90	0.43	10.920 0	0.180 0	0.481 8	0.009 9	0.164 5	0.002 5	2.516	16	2.534	43	2.500	25	99
21ZT22-1-77	40.10	17.60	67.70	0.26	10.880 0	0.230 0	0.483 7	0.011 0	0.165 0	0.003 7	2.510	19	2.542	48	2.499	38	99
21ZT22-1-14	52.60	31.00	90.50	0.34	10.710 0	0.160 0	0.468 5	0.008 9	0.164 4	0.001 8	2.495	13	2.476	39	2.499	19	99
21ZT22-1-94	63.00	84.30	93.70	0.90	10.770 0	0.260 0	0.476 8	0.012 0	0.165 1	0.004 7	2.501	22	2.512	51	2.498	47	100
21ZT22-1-91	33.50	22.40	55.60	0.40	10.910 0	0.210 0	0.480 4	0.009 9	0.164 5	0.002 7	2.511	18	2.527	43	2.498	26	99
21ZT22-1-157	141.00	156.50	243.70	0.64	10.890 0	0.220 0	0.480 1	0.011 0	0.164 4	0.002 4	2.512	19	2.527	48	2.498	24	99
21ZT22-1-104	63.90	55.20	101.70	0.54	10.810 0	0.150 0	0.473 6	0.009 3	0.164 7	0.002 3	2.504	13	2.498	41	2.498	24	100
21ZT22-1-92	100.30	108.60	156.40	0.69	10.870 0	0.140 0	0.479 0	0.009 4	0.164 4	0.002 0	2.510	12	2.522	41	2.497	21	100
21ZT22-1-148	42.80	38.20	69.40	0.55	10.930 0	0.200 0	0.476 8	0.009 4	0.164 8	0.002 7	2.513	17	2.512	41	2.497	27	100
21ZT22-1-146	64.50	43.40	106.30	0.41	10.890 0	0.160 0	0.478 8	0.009 8	0.164 4	0.002 2	2.511	14	2.521	43	2.497	23	100
21ZT22-1-105	49.30	34.30	81.20	0.42	10.950 0	0.170 0	0.481 7	0.009 6	0.164 1	0.002 4	2.517	14	2.534	41	2.497	26	99
21ZT22-1-136	56.70	42.50	93.10	0.46	10.890 0	0.170 0	0.478 8	0.009 4	0.164 6	0.002 4	2.515	14	2.521	41	2.496	25	100
21ZT22-1-122	123.50	86.80	205.90	0.42	10.830 0	0.120 0	0.476 0	0.009 0	0.164 0	0.001 6	2.507	10	2.509	39	2.496	16	100
21ZT22-1-117	48.50	49.90	77.70	0.64	10.800 0	0.170 0	0.473 7	0.009 4	0.164 5	0.002 4	2.503	15	2.499	41	2.496	24	100
21ZT22-1-113	63.60	67.60	100.60	0.67	10.840 0	0.140 0	0.475 9	0.009 4	0.164 5	0.002 2	2.507	12	2.508	41	2.496	23	100
21ZT22-1-15	55.60	39.40	92.00	0.43	10.860 0	0.150 0	0.477 9	0.009 3	0.164 3	0.002 1	2.509	13	2.517	41	2.495	22	100
21ZT22-1-26	35.70	25.10	59.20	0.42	10.880 0	0.290 0	0.478 8	0.011 0	0.164 6	0.004 1	2.514	26	2.521	48	2.494	43	100
21ZT22-1-151	73.10	77.70	114.90	0.68	10.870 0	0.130 0	0.479 0	0.009 2	0.164 0	0.001 7	2.511	11	2.522	40	2.493	18	100
21ZT22-1-125	48.20	38.20	79.50	0.48	10.750 0	0.170 0	0.474 2	0.009 6	0.164 2	0.002 6	2.501	15	2.501	42	2.493	27	100
21ZT22-1-12	95.00	32.30	165.50	0.19	10.890 0	0.120 0	0.478 9	0.009 0	0.163 9	0.001 7	2.512	10	2.522	39	2.493	18	100
21ZT22-1-119	73.90	79.20	122.20	0.65	10.810 0	0.250 0	0.475 5	0.011 0	0.163 7	0.002 5	2.502	22	2.506	47	2.493	27	100
21ZT22-1-11	35.10	34.10	55.20	0.62	11.140 0	0.210 0	0.489 7	0.011 0	0.163 4	0.003 2	2.531	18	2.568	46	2.492	33	99
21ZT22-1-109	36.70	27.80	60.00	0.46	10.800 0	0.260 0	0.477 5	0.011 0	0.164 2	0.003 1	2.502	22	2.515	46	2.492	32	99
21ZT22-1-103	45.10	46.30	70.80	0.65	11.000 0	0.250 0	0.487 5	0.011 0	0.164 1	0.003 6	2.521	21	2.559	45	2.492	37	99
21ZT22-1-69	139.80	143.60	229.30	0.63	10.780 0	0.190 0	0.475 2	0.010 0	0.163 8	0.002 1	2.502	17	2.511	47	2.491	21	100
21ZT22-1-135	46.40	35.00	76.30	0.46	10.870 0	0.170 0	0.478 4	0.009 4	0.164 1	0.002 5	2.509	14	2.520	41	2.491	26	100
21ZT22-1-131	65.10	68.60	103.10	0.67	10.780 0	0.160 0	0.474 9	0.009 4	0.163 9	0.002 1	2.503	13	2.507	42	2.491	22	100
21ZT22-1-112	49.80	40.90	81.50	0.50	10.790 0	0.150 0	0.475 7	0.009 2	0.164 0	0.002 3	2.504	13	2.508	40	2.491	24	100

续表 2-4
Continued Table 2-4

样品号	$w_B/10^{-6}$			Th/U	同位素比值				年龄/Ma				谐和度/%				
	Total Pb	²³² Th	²³⁸ U		²⁰⁶ Pb/ ²³⁸ U		²⁰⁷ Pb/ ²³⁵ U		²⁰⁶ Pb/ ²³⁸ U		²⁰⁷ Pb/ ²³⁵ U						
					2σ	2σ	2σ	2σ	2σ	2σ	2σ	2σ					
21ZT22-1-142	71.20	68.80	113.50	0.61	10.860 0	0.150 0	0.478 7	0.009 0	0.163 6	0.002 1	2.509	13	2.523	38	2.490	21	99
21ZT22-1-132	53.60	30.20	95.60	0.32	10.840 0	0.160 0	0.477 6	0.009 4	0.164 0	0.002 3	2.507	14	2.516	41	2.490	24	100
21ZT22-1-6	82.70	62.10	135.90	0.46	10.880 0	0.140 0	0.478 9	0.009 4	0.163 3	0.001 9	2.511	12	2.522	41	2.489	19	100
21ZT22-1-156	83.80	58.10	140.30	0.41	10.770 0	0.210 0	0.475 8	0.011 0	0.163 6	0.002 9	2.501	18	2.508	49	2.489	30	100
21ZT22-1-149	65.20	61.40	103.50	0.59	10.820 0	0.180 0	0.478 7	0.009 1	0.163 6	0.002 6	2.506	16	2.521	40	2.488	27	99
21ZT22-1-118	22.60	19.00	36.50	0.52	10.870 0	0.210 0	0.480 8	0.010 0	0.164 4	0.003 4	2.512	19	2.529	45	2.488	35	99
21ZT22-1-145	10.80	11.50	17.50	0.66	10.680 0	0.350 0	0.474 0	0.012 0	0.164 1	0.005 5	2.494	30	2.498	54	2.487	58	100
21ZT22-1-140	35.40	30.10	57.20	0.53	10.830 0	0.180 0	0.479 0	0.009 7	0.163 0	0.002 6	2.508	15	2.522	42	2.487	27	99
21ZT22-1-98	27.80	23.20	44.60	0.52	11.080 0	0.380 0	0.486 0	0.013 0	0.164 2	0.005 2	2.528	34	2.553	57	2.485	51	99
21ZT22-1-7	45.30	45.60	73.60	0.62	10.720 0	0.190 0	0.471 5	0.009 9	0.163 5	0.002 9	2.496	16	2.489	43	2.484	30	100
21ZT22-1-2	364.10	1 433.00	462.70	3.10	9.040 0	0.230 0	0.398 4	0.010 0	0.162 8	0.002 7	2.340	23	2.161	47	2.482	28	92
21ZT22-1-101	89.40	148.40	289.20	0.51	5.290 0	0.140 0	0.235 4	0.006 3	0.162 1	0.002 8	1.863	22	1.362	33	2.477	28	69
21ZT22-1-1	86.80	92.40	147.90	0.62	10.790 0	0.180 0	0.476 0	0.009 5	0.162 5	0.002 2	2.503	15	2.509	41	2.477	23	100
21ZT22-1-62	288.80	286.40	690.00	0.42	7.520 0	0.260 0	0.341 0	0.011 0	0.162 1	0.003 9	2.173	32	1.890	53	2.474	41	86
21ZT22-1-143	166.90	162.70	320.80	0.51	8.900 0	0.110 0	0.396 8	0.007 6	0.161 9	0.001 6	2.326	12	2.154	35	2.472	17	92
21ZT22-1-120	54.50	42.00	90.70	0.46	10.770 0	0.260 0	0.474 3	0.011 0	0.161 8	0.003 4	2.501	22	2.501	47	2.469	35	100
21ZT22-1-116	39.70	27.10	67.40	0.40	10.630 0	0.320 0	0.469 9	0.011 0	0.162 3	0.005 0	2.486	27	2.482	49	2.467	51	100
变质锆石																	
21ZT22-1-152	158.80	105.80	281.00	0.38	10.680 0	0.190 0	0.467 0	0.010 0	0.164 9	0.002 6	2.495	17	2.470	45	2.503	26	99
21ZT22-1-153	39.30	22.50	67.10	0.34	10.640 0	0.350 0	0.474 0	0.014 0	0.161 2	0.003 9	2.489	30	2.500	59	2.464	41	100
21ZT22-1-154	70.00	54.50	116.20	0.47	10.810 0	0.150 0	0.472 9	0.009 0	0.164 5	0.002 1	2.505	13	2.496	39	2.497	21	100
21ZT22-1-155	45.50	25.70	76.20	0.34	10.890 0	0.220 0	0.475 8	0.011 0	0.164 6	0.004 3	2.511	19	2.508	48	2.495	44	100
21ZT22-1-3	278.90	674.20	319.60	2.11	11.250 0	0.160 0	0.492 0	0.010 0	0.164 8	0.002 1	2.543	13	2.579	45	2.502	22	99
21ZT22-1-9	65.60	55.20	107.80	0.51	10.710 0	0.190 0	0.473 6	0.010 0	0.162 3	0.003 2	2.496	17	2.498	44	2.473	34	100
21ZT22-1-37	147.70	80.40	247.60	0.32	10.840 0	0.140 0	0.479 8	0.009 3	0.166 1	0.001 9	2.508	12	2.526	40	2.484	40	99
21ZT22-1-66	33.20	24.90	57.70	0.43	11.040 0	0.180 0	0.480 4	0.009 5	0.167 7	0.002 5	2.523	15	2.528	41	2.527	25	100
21ZT22-1-67	133.70	75.60	223.50	0.34	10.900 0	0.120 0	0.480 6	0.009 3	0.165 7	0.001 9	2.513	10	2.529	40	2.510	19	99
21ZT22-1-80	60.90	49.50	97.40	0.51	10.870 0	0.220 0	0.479 4	0.011 0	0.166 1	0.003 1	2.513	20	2.524	49	2.519	34	100
21ZT22-1-147	74.50	51.80	127.90	0.40	10.820 0	0.250 0	0.470 4	0.012 0	0.164 8	0.003 2	2.505	21	2.484	50	2.500	33	99
21ZT22-1-158	44.40	41.20	73.60	0.56	10.790 0	0.270 0	0.472 2	0.011 0	0.162 8	0.003 5	2.500	23	2.498	50	2.476	37	100

表3 赞皇杂岩官都岩群黑云变粒岩锆石稀土元素分析结果

Table 3 Rare earth element compositions of zircons from the biotite leptynites of the Guandu Group in the Zanhua Complex

样品号	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Σ REE	Eu/Eu*	Ce/Ce*	La _N /Sm _N
碎屑锆石																		
21ZT20-1-5	0.184	10.630	0.456	6.300	11.600	2.350	74.900	24.200	314.100	119.100	558.000	114.500	968.000	194.200	2 398.52	0.18	6.23	100.84
21ZT20-1-2	0.120	17.920	0.037	0.800	1.870	0.682	8.790	2.360	28.610	10.990	55.900	12.720	127.500	30.810	299.11	0.43	65.37	99.24
21ZT20-1-9	0.813	9.100	0.546	2.670	1.900	0.790	9.250	3.290	49.300	22.210	133.600	33.650	374.500	94.600	736.22	0.47	3.24	299.91
21ZT20-1-90	1.050	32.800	0.970	5.300	4.100	1.680	14.500	4.340	53.700	20.240	104.500	24.710	255.700	62.100	585.69	0.60	7.32	91.24
21ZT20-1-83	0.052	40.000	0.062	1.130	1.990	0.830	11.770	3.670	48.300	19.340	104.200	24.070	247.300	56.900	559.61	0.41	149.90	172.23
21ZT20-1-38	0.072	11.460	0.143	3.100	7.800	2.450	48.700	13.930	155.200	50.700	222.900	41.500	338.000	65.000	960.96	0.29	20.70	50.20
21ZT20-1-12	0.093	17.370	0.049	1.090	2.380	0.990	11.920	3.560	41.400	16.150	80.900	18.490	178.500	42.800	415.69	0.46	62.47	108.32
21ZT20-1-77	2.320	104.700	2.030	10.900	10.100	1.570	37.200	12.420	156.800	57.200	293.000	60.000	553.000	113.800	1 415.04	0.22	10.98	67.87
21ZT20-1-129	1.580	29.100	1.470	7.700	7.700	3.030	23.900	6.610	73.500	26.400	136.200	30.400	306.000	71.300	724.89	0.63	4.30	55.78
21ZT20-1-110	0.023	28.960	0.515	7.960	11.330	1.970	40.200	10.260	112.200	37.490	173.900	33.470	301.000	60.600	819.88	0.25	17.15	32.22
21ZT20-1-130	0.086	4.580	0.094	1.690	3.670	0.511	25.600	8.880	117.600	46.400	234.300	45.700	412.000	84.000	985.11	0.12	11.07	137.87
21ZT20-1-58	0.076	20.520	0.065	1.010	2.440	0.900	13.370	4.090	47.200	17.940	90.300	19.110	183.300	42.580	442.90	0.38	66.59	105.12
21ZT20-1-19	0.116	34.200	0.316	4.340	5.590	2.010	23.300	6.430	68.100	23.300	109.700	23.560	221.600	47.600	570.16	0.46	29.29	51.29
21ZT20-1-36	0.124	5.800	0.216	3.590	6.540	0.840	42.700	14.670	184.600	71.200	334.000	64.600	549.000	109.400	1387.28	0.12	6.78	100.76
21ZT20-1-59	0.167	2.950	0.030	0.730	2.110	0.830	13.080	4.110	52.600	19.820	100.400	21.130	198.400	45.100	461.46	0.37	9.45	128.75
21ZT20-1-123	0.172	42.800	0.580	7.800	13.600	5.200	53.200	13.000	131.000	37.100	158.500	32.300	304.500	65.200	865.55	0.52	20.48	28.88
21ZT20-1-3	0.014	35.500	0.076	1.260	3.100	1.700	17.400	4.910	55.700	20.800	100.200	22.700	220.000	50.400	533.76	0.56	135.04	97.93
21ZT20-1-82	0.116	47.400	0.224	3.360	5.120	1.740	22.200	6.570	75.400	28.100	141.400	31.200	311.000	70.000	743.83	0.42	54.40	82.35
21ZT20-1-124	0.085	11.500	0.078	1.470	3.570	0.266	18.580	5.740	67.300	24.100	113.000	21.680	189.400	36.570	493.34	0.08	31.79	61.70
21ZT20-1-88	0.033	41.900	0.175	2.830	5.290	1.860	23.200	6.880	76.900	28.500	137.300	29.900	283.300	63.400	701.47	0.43	69.11	72.19
21ZT20-1-89	0.331	35.100	0.329	2.020	3.020	1.340	13.300	3.810	42.000	14.080	69.100	15.580	159.400	37.200	396.61	0.55	23.60	74.20
21ZT20-1-102	0.240	44.700	0.055	1.380	2.690	0.718	13.270	4.100	48.300	17.700	87.800	19.100	185.600	38.690	464.34	0.30	91.78	86.64
21ZT20-1-117	0.199	23.850	0.171	2.230	3.650	0.790	16.200	4.630	51.100	17.890	85.400	17.680	167.400	34.720	425.91	0.27	29.53	57.30
21ZT20-1-39	0.016	30.150	0.051	0.990	1.810	0.733	9.280	2.810	33.000	12.740	64.700	14.530	148.500	35.080	354.39	0.44	163.03	116.75
21ZT20-1-80	3.450	72.800	1.380	9.370	9.400	2.280	34.200	9.790	109.000	39.430	195.900	40.930	385.600	83.600	997.13	0.35	8.18	53.57
21ZT20-1-61	0.245	28.930	0.064	0.910	2.240	0.526	11.160	3.200	35.900	13.220	64.900	13.830	130.900	28.650	334.68	0.26	55.37	77.04
21ZT20-1-126	0.379	42.100	0.243	3.690	5.770	1.960	22.900	5.980	66.900	23.800	117.400	25.450	250.900	57.000	624.47	0.45	33.10	59.51
21ZT20-1-10	2.120	35.700	1.490	8.400	5.420	2.080	16.600	4.640	52.900	19.370	100.800	23.960	244.800	59.000	577.28	0.62	4.74	65.57
21ZT20-1-75	0.456	33.400	0.027	0.890	1.480	0.601	8.240	2.660	33.300	13.890	76.700	18.460	199.000	50.400	439.50	0.42	49.43	205.13
21ZT20-1-34	0.356	6.350	0.050	0.780	1.720	0.431	10.840	3.310	43.100	16.550	85.200	18.760	173.500	40.200	401.15	0.23	10.23	140.78
21ZT20-1-57	0.277	48.500	1.073	13.560	21.000	7.520	90.000	23.800	254.000	82.600	364.000	70.100	611.000	120.200	1 707.63	0.45	12.72	34.48
21ZT20-1-113	0.343	51.800	0.234	2.130	3.560	1.490	17.800	5.860	70.800	27.600	145.900	32.940	342.200	79.700	782.36	0.47	43.29	134.85
21ZT20-1-11	0.035	52.400	0.159	2.940	5.160	2.430	28.000	7.640	87.000	29.770	136.500	27.700	247.700	53.900	681.33	0.49	94.02	62.92
21ZT20-1-14	4.500	99.200	4.120	19.800	13.750	5.600	32.500	9.930	90.600	24.290	103.700	21.520	206.700	43.400	679.61	0.78	5.20	19.01
21ZT20-1-106	0.315	49.800	1.045	12.800	17.660	7.330	62.300	15.850	162.100	51.800	232.700	47.000	430.000	91.300	1 182.00	0.60	13.20	31.14
21ZT20-1-31	0.083	33.400	0.091	1.010	1.710	0.625	9.920	2.950	40.200	16.100	87.600	20.520	216.000	52.100	482.31	0.36	83.44	183.53
21ZT20-1-45	0.145	24.410	0.108	1.470	2.550	0.631	10.420	3.060	32.400	11.390	54.000	11.770	110.100	23.980	286.43	0.32	45.62	56.65
21ZT20-1-1	0.210	38.700	0.620	7.500	8.000	3.200	29.800	7.340	78.100	27.500	128.200	26.200	251.000	57.800	664.17	0.56	17.06	43.52
21ZT20-1-84	22.500	350.000	18.500	86.800	58.000	22.200	123.000	35.300	318.000	81.100	334.000	65.500	605.000	117.100	2 237.00	0.78	3.95	12.16
21ZT20-1-22	0.390	41.400	0.780	7.500	14.200	10.600	72.000	18.500	167.000	43.200	166.000	31.200	288.000	62.100	922.87	0.82	13.73	26.34
21ZT20-1-63	0.085	41.800	0.039	0.970	2.720	0.760	15.400	4.960	59.000	22.500	112.400	24.860	228.900	47.700	562.09	0.28	177.59	105.63

续表 3-1
Continued Table 3-1

样品号	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	ΣREE	Eu/Eu [*] Ce/Ce [*]	La _N /Sm _N
21ZT20-1-99	0.067 0	38.300 0	0.074 0	1.430 0	2.820 0	0.920 0	14.080 0	4.340 0	51.200 0	19.910 0	104.400 0	23.070 0	225.500 0	50.800 0	536.91	0.36	117.90
21ZT20-1-47	0.052 0	33.830 0	0.174 0	2.290 0	3.410 0	0.780 0	16.300 0	4.200 0	47.500 0	17.260 0	83.500 0	16.560 0	159.000 0	33.280 0	418.14	0.26	53.90
21ZT20-1-13	0.085 0	10.230 0	0.074 0	2.090 0	3.550 0	0.387 0	19.700 0	5.960 0	71.500 0	25.100 0	114.700 0	22.000 0	185.700 0	37.330 0	498.41	0.11	29.39
21ZT20-1-29	0.310 0	24.810 0	0.417 0	3.920 0	4.010 0	1.270 0	16.700 0	5.000 0	58.500 0	23.090 0	120.800 0	27.680 0	280.200 0	65.400 0	632.11	0.41	14.23
21ZT20-1-46	1.040 0	32.600 0	0.880 0	5.310 0	5.760 0	2.600 0	22.200 0	6.900 0	78.800 0	30.000 0	147.200 0	32.500 0	324.000 0	73.300 0	763.09	0.62	7.80
21ZT20-1-98	1.240 0	42.900 0	0.640 0	5.370 0	11.500 0	6.750 0	48.400 0	11.930 0	103.600 0	28.900 0	122.500 0	25.900 0	258.900 0	60.300 0	728.83	0.75	11.71
21ZT20-1-108	0.580 0	49.400 0	0.500 0	2.660 0	3.390 0	1.530 0	14.700 0	4.210 0	49.700 0	18.960 0	98.500 0	21.600 0	226.200 0	53.200 0	545.13	0.56	20.94
21ZT20-1-111	0.460 0	40.900 0	0.158 0	2.980 0	5.400 0	1.900 0	29.100 0	9.280 0	113.700 0	43.000 0	220.200 0	47.600 0	462.000 0	99.200 0	1 075.88	0.37	37.09
21ZT20-1-116	0.260 0	25.800 0	0.080 0	1.640 0	3.130 0	1.270 0	14.990 0	4.310 0	50.800 0	18.930 0	96.400 0	20.990 0	211.600 0	47.600 0	497.80	0.47	43.48
21ZT20-1-8	0.070 0	32.100 0	0.113 0	1.960 0	3.060 0	1.240 0	13.400 0	3.950 0	45.800 0	17.010 0	89.800 0	21.100 0	213.700 0	48.200 0	491.50	0.50	70.65
21ZT20-1-26	5.100 0	24.300 0	2.760 0	15.000 0	9.800 0	2.080 0	39.300 0	10.310 0	109.900 0	35.400 0	155.600 0	28.600 0	239.500 0	48.200 0	725.85	0.28	1.57
21ZT20-1-27	0.360 0	49.100 0	0.389 0	3.620 0	5.220 0	2.010 0	23.800 0	6.080 0	79.200 0	29.260 0	139.800 0	30.350 0	286.500 0	63.700 0	719.99	0.46	28.58
21ZT20-1-49	1.930 0	62.100 0	2.130 0	12.900 0	9.890 0	3.600 0	34.300 0	9.250 0	94.300 0	30.000 0	136.500 0	28.500 0	270.500 0	58.100 0	754.00	0.54	6.64
21ZT20-1-96	12.300 0	225.000 0	10.300 0	48.700 0	32.000 0	11.490 0	85.400 0	21.500 0	217.500 0	69.800 0	327.200 0	66.500 0	637.000 0	135.200 0	1 899.89	0.63	4.59
21ZT20-1-6	0.078 0	8.180 0	0.045 0	0.850 0	2.080 0	0.391 0	13.400 0	4.000 0	51.400 0	19.400 0	91.500 0	18.370 0	155.800 0	32.100 0	397.59	0.17	33.30
21ZT20-1-25	0.085 0	13.350 0	0.098 0	1.560 0	3.980 0	0.348 0	20.200 0	6.360 0	74.100 0	26.530 0	119.500 0	23.070 0	195.600 0	38.130 0	522.91	0.10	31.38
21ZT20-1-41	0.065 0	7.310 0	0.112 0	2.580 0	5.480 0	0.850 0	41.600 0	14.740 0	193.800 0	77.200 0	373.200 0	73.800 0	642.700 0	131.900 0	1 565.34	0.12	16.44
21ZT20-1-105	2.110 0	59.500 0	1.750 0	9.600 0	7.800 0	2.630 0	22.400 0	6.320 0	67.200 0	24.100 0	121.700 0	27.200 0	281.100 0	64.000 0	697.41	0.57	7.12
21ZT20-1-35	0.048 0	41.1400	0.041 0	0.950 0	2.380 0	0.583 0	9.660 0	3.120 0	35.700 0	12.970 0	63.900 0	14.120 0	133.700 0	28.580 0	346.89	0.32	212.02
21ZT20-1-94	0.057 0	20.190 0	0.086 0	1.750 0	2.610 0	1.280 0	13.480 0	3.710 0	40.200 0	14.720 0	70.700 0	15.860 0	159.300 0	35.940 0	379.88	0.53	57.59
21ZT20-1-121	0.022 0	4.160 0	0.075 0	0.960 0	2.460 0	0.662 0	13.900 0	4.360 0	51.600 0	18.360 0	84.900 0	16.770 0	147.900 0	30.190 0	376.32	0.27	15.41
21ZT20-1-17	1.340 0	38.900 0	1.750 0	10.620 0	10.370 0	5.240 0	33.100 0	9.910 0	105.200 0	33.660 0	158.400 0	34.270 0	325.700 0	72.100 0	840.56	0.79	5.28
21ZT20-1-28	0.055 0	39.400 0	0.155 0	1.840 0	3.450 0	1.210 0	15.400 0	4.230 0	47.100 0	17.500 0	88.000 0	20.200 0	201.000 0	46.100 0	485.64	0.43	69.09
21ZT20-1-56	1.750 0	32.100 0	1.330 0	7.700 0	4.770 0	1.530 0	15.100 0	4.250 0	46.700 0	17.150 0	89.700 0	20.250 0	211.600 0	50.500 0	504.43	0.50	4.91
21ZT20-1-71	0.001 0	26.650 0	0.039 0	0.770 0	1.880 0	0.625 0	9.040 0	2.770 0	33.400 0	12.580 0	67.400 0	15.560 0	155.100 0	36.660 0	362.48	0.38	209.99
21ZT20-1-107	0.006 0	35.720 0	0.069 0	1.380 0	2.890 0	0.920 0	11.890 0	3.610 0	41.300 0	16.300 0	84.600 0	18.730 0	196.200 0	45.270 0	458.89	0.41	155.30
21ZT20-1-42	0.168 0	49.100 0	0.307 0	3.790 0	5.720 0	2.250 0	22.300 0	6.610 0	70.900 0	25.900 0	125.900 0	27.300 0	263.700 0	60.000 0	663.95	0.53	40.72
21ZT20-1-55	0.224 0	32.100 0	0.299 0	2.970 0	5.320 0	0.590 0	26.400 0	8.300 0	97.500 0	34.800 0	155.800 0	30.480 0	249.700 0	48.200 0	692.68	0.12	25.63
21ZT20-1-91	3.270 0	47.100 0	1.800 0	11.500 0	8.100 0	2.780 0	24.700 0	6.930 0	75.700 0	26.300 0	123.000 0	28.220 0	276.000 0	62.800 0	698.20	0.55	4.70
21ZT20-1-97	2.050 0	34.700 0	0.950 0	5.000 0	3.850 0	1.300 0	20.200 0	5.800 0	66.600 0	25.200 0	123.600 0	27.500 0	276.000 0	53.500 0	646.25	0.36	6.08
21ZT20-1-109	1.360 0	58.900 0	1.240 0	8.000 0	6.080 0	2.330 0	20.800 0	6.190 0	68.100 0	23.600 0	119.800 0	26.510 0	272.900 0	63.300 0	679.11	0.57	10.24
21ZT20-1-93	0.072 0	63.200 0	0.388 0	6.430 0	10.140 0	1.780 0	42.300 0	11.670 0	127.900 0	43.800 0	203.000 0	39.200 0	340.300 0	68.400 0	958.58	0.23	47.07
21ZT20-1-104	0.022 0	13.510 0	0.060 0	1.100 0	1.880 0	0.795 0	11.190 0	3.480 0	41.500 0	16.190 0	83.000 0	18.810 0	188.100 0	44.100 0	423.74	0.41	60.95
21ZT20-1-85	0.770 0	39.500 0	0.620 0	8.010 0	8.970 0	2.050 0	32.200 0	7.970 0	80.300 0	25.040 0	104.500 0	19.540 0	160.300 0	31.000 0	520.77	0.33	13.21
21ZT20-1-7	24.100 0	84.400 0	7.300 0	30.200 0	8.010 0	1.510 0	20.900 0	5.490 0	60.700 0	21.860 0	109.600 0	24.560 0	235.600 0	53.800 0	688.03	0.34	1.54
21ZT20-1-50	0.260 0	77.200 0	0.400 0	4.490 0	6.890 0	2.530 0	32.000 0	8.960 0	104.600 0	37.300 0	176.200 0	36.300 0	336.000 0	69.600 0	892.73	0.43	47.53
21ZT20-1-51	0.440 0	25.000 0	0.380 0	2.570 0	3.050 0	1.240 0	13.400 0	3.870 0	43.300 0	15.430 0	78.600 0	17.520 0	177.000 0	42.800 0	424.60	0.50	13.95
21ZT20-1-87	0.193 0	29.700 0	0.426 0	3.180 0	2.930 0	2.610 0	13.310 0	4.180 0	50.700 0	19.790 0	99.700 0	21.710 0	217.300 0	49.100 0	514.83	1.07	18.32
21ZT20-1-103	0.418 0	40.000 0	0.437 0	3.730 0	4.500 0	1.440 0	17.700 0	5.160 0	57.800 0	21.020 0	105.600 0	23.240 0	228.100 0	50.230 0	559.38	0.43	20.54
21ZT20-1-128	0.256 0	28.800 0	0.093 0	1.960 0	3.730 0	0.950 0	17.200 0	4.980 0	58.400 0	20.500 0	104.000 0	21.740 0	208.900 0	44.800 0	516.31	0.30	45.71
21ZT20-1-66	0.046 8	25.590 0	0.220 0	3.370 0	5.140 0	1.410 0	20.100 0	5.250 0	54.000 0	18.460 0	83.900 0	17.470 0	164.100 0	35.280 0	434.34	0.37	33.27
21ZT20-1-68	0.022 0	13.610 0	0.038 0	0.930 0	1.750 0	0.734 0	9.000 0	2.640 0	30.100 0	11.590 0	59.300 0	13.420 0	133.800 0	31.900 0	308.83	0.46	90.25

续表 3-2
Continued Table 3-2

样品号	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Σ REE	Eu/Eu*	Ce/Ce*	La _N /Sm _N
21ZT20-1-70	0.084	0.63	0.200	0.746	0.746	0.746	0.746	0.746	0.746	0.746	0.746	0.746	0.746	0.746	0.746	0.45	25.17	37.29
21ZT20-1-92	1.070	54.600	0.920	0.920	0.920	0.920	0.920	0.920	0.920	0.920	0.920	0.920	0.920	0.920	0.920	0.66	12.57	63.64
21ZT20-1-30	1.090	58.000	1.090	1.090	1.090	1.090	1.090	1.090	1.090	1.090	1.090	1.090	1.090	1.090	1.090	0.48	11.79	41.29
21ZT20-1-40	0.726	58.500	0.698	0.698	0.698	0.698	0.698	0.698	0.698	0.698	0.698	0.698	0.698	0.698	0.698	0.57	18.36	40.95
21ZT20-1-119	4.140	116.400	2.860	17.800	19.100	8.980	63.900	17.290	180.000	59.100	274.500	54.900	505.000	101.500	1425.47	0.71	8.00	32.01
21ZT20-1-52	0.480	29.800	0.250	3.780	6.990	1.720	28.600	7.560	77.600	27.600	129.100	26.800	243.000	52.300	635.58	0.32	20.91	45.07
21ZT20-1-54	0.890	59.600	0.782	8.470	11.330	3.070	43.300	11.050	114.300	38.440	177.900	37.440	334.400	71.000	911.97	0.37	16.25	37.75
21ZT20-1-76	0.530	31.000	0.600	5.440	5.320	2.660	19.200	5.290	54.900	17.600	81.200	17.000	167.000	37.500	445.24	0.72	11.85	42.46
21ZT20-1-32	0.067	40.000	0.536	5.510	9.910	1.620	43.800	11.740	128.300	44.400	190.600	36.100	301.700	58.800	873.08	0.20	22.06	35.74
21ZT20-1-48	0.165	25.740	0.780	12.700	30.700	13.400	128.000	28.900	218.000	51.100	176.000	28.900	230.500	43.910	988.80	0.56	9.44	8.62
21ZT20-1-64	8.090	162.400	6.600	33.200	24.500	10.000	62.800	19.100	180.000	46.800	187.600	36.100	321.900	63.500	1162.59	0.74	5.12	15.61
21ZT20-1-73	0.459	50.500	0.910	10.210	14.200	3.820	61.700	16.390	175.500	57.400	257.700	49.800	443.000	87.600	1229.19	0.34	14.33	37.16
21ZT20-1-78	0.045	52.100	0.184	2.720	4.920	1.350	19.400	5.560	63.100	22.020	106.500	22.490	211.900	45.140	557.43	0.37	80.06	55.27
21ZT20-1-112	3.300	66.200	3.140	19.800	16.100	5.440	49.600	13.650	132.500	41.600	187.900	38.100	368.000	79.500	1024.83	0.54	4.61	29.74
21ZT20-1-115	6.010	93.100	5.040	28.900	21.900	8.540	56.500	14.520	143.700	45.300	207.300	44.380	429.600	90.500	1195.29	0.70	3.88	24.89
21ZT20-1-16	0.920	40.700	0.649	6.900	9.500	7.770	61.200	17.200	154.000	40.000	161.400	32.000	299.000	68.500	899.74	0.74	12.41	43.43
21ZT20-1-44	0.038	42.420	0.238	3.730	5.940	1.590	23.800	6.630	74.400	26.680	127.700	27.150	256.200	54.400	650.92	0.35	52.01	55.17
21ZT20-1-120	0.169	23.090	0.174	1.040	1.170	0.760	5.960	1.870	20.300	6.800	34.500	7.970	85.600	19.870	209.47	0.72	29.65	102.30
21ZT20-1-53	0.068	76.800	0.363	5.670	9.160	1.180	40.200	10.930	118.900	41.100	181.400	35.100	303.000	62.000	885.87	0.16	61.10	40.77
21ZT20-1-37	0.770	56.200	0.940	9.900	13.300	3.870	53.600	13.250	140.100	45.700	196.100	40.600	356.000	72.500	1002.83	0.38	13.97	32.84
21ZT20-1-114	0.430	29.850	0.400	3.500	3.960	1.450	17.250	4.900	57.600	21.640	110.000	25.190	255.100	57.700	588.97	0.46	16.19	87.77
21ZT20-1-127	8.300	114.000	4.800	23.200	16.900	6.700	44.900	12.900	122.000	35.400	155.000	32.300	297.000	62.400	935.80	0.70	4.35	22.24
21ZT20-1-20	0.580	34.100	1.090	12.000	13.900	4.870	60.300	14.840	151.200	48.300	208.900	38.600	322.000	62.800	973.48	0.44	8.01	27.21
21ZT20-1-86	1.260	133.800	1.200	10.800	14.230	7.080	54.100	15.390	157.600	49.900	223.200	45.000	400.000	81.400	1194.96	0.69	24.36	34.46
21ZT20-1-15	0.560	48.500	0.870	7.200	9.100	5.060	30.100	8.680	92.800	30.600	156.200	34.600	339.700	75.900	839.87	0.85	13.76	50.24
21ZT20-1-79	0.025	59.100	0.317	4.780	7.370	2.420	26.700	6.780	70.300	22.300	99.900	19.930	179.700	36.700	536.32	0.47	56.11	30.00
21ZT20-1-69	10.360	207.000	8.610	43.800	31.100	12.530	73.900	22.500	203.000	51.700	208.100	41.800	389.000	75.000	1378.40	0.77	5.04	14.53
21ZT20-1-62	0.040	11.990	0.364	3.780	4.390	2.160	14.100	3.530	32.900	10.360	43.800	8.960	81.300	16.600	234.27	0.77	9.79	22.78
21ZT20-1-4	6.310	79.800	4.350	21.700	12.600	4.860	32.900	9.000	86.400	24.800	114.900	24.220	235.400	50.500	707.74	0.69	3.60	24.14
21ZT20-1-67	1.350	64.200	1.570	12.900	13.200	5.230	40.600	10.880	112.100	36.100	166.500	35.700	351.600	79.400	931.33	0.64	9.44	36.23
21ZT20-1-122	0.146	6.650	0.048	1.340	2.660	0.373	14.990	5.000	57.400	21.180	97.900	18.620	165.200	32.200	423.71	0.14	19.38	72.92
21ZT20-1-60	2.740	68.900	1.580	10.360	9.060	4.460	29.400	7.000	71.000	22.830	107.800	22.960	213.400	44.940	616.43	0.76	7.99	29.88
21ZT20-1-100	2.890	65.800	1.940	12.000	8.200	5.220	22.500	5.590	56.800	17.550	85.800	18.290	180.200	40.300	523.08	1.10	6.59	29.60
21ZT20-1-18	0.690	31.400	0.787	8.300	12.400	5.230	57.300	14.500	151.200	44.800	189.000	36.200	309.000	60.900	921.71	0.50	9.17	29.58
21ZT20-1-24	1.350	48.100	0.647	5.410	6.390	2.420	26.400	7.100	82.700	30.880	156.300	34.510	348.000	78.800	829.01	0.49	12.57	74.28
21ZT20-1-43	3.000	83.700	2.220	14.900	14.600	5.440	46.600	12.570	130.900	43.600	199.800	41.150	384.600	83.400	1066.48	0.58	7.59	34.41
21ZT20-1-65	1.760	61.500	1.340	8.510	9.650	5.570	33.500	9.360	94.600	30.100	141.700	29.200	284.100	60.300	771.19	0.88	9.33	42.68
21ZT20-1-72	2.180	72.300	2.240	16.500	19.700	9.270	74.100	20.500	198.300	56.200	242.300	50.600	477.000	100.000	1341.19	0.65	7.21	30.58
21ZT20-1-101	2.190	135.100	2.080	13.400	15.000	8.510	51.700	14.590	150.800	48.300	216.800	44.000	393.200	80.200	1175.87	0.84	14.18	32.21
21ZT20-1-74	5.530	112.900	3.830	20.500	15.000	20.300	42.300	11.020	113.400	36.800	173.800	36.600	350.000	75.100	1017.08	2.30	5.80	30.16
变质型碎屑岩石																		
21ZT20-1-23	0.033	15.980	0.539	8.700	12.850	1.590	49.200	13.840	150.200	50.000	220.300	41.920	350.900	71.400	987.45	0.17	8.98	33.47
21ZT20-1-81	0.047	7.650	0.161	2.230	4.390	0.710	20.100	6.110	72.100	25.830	117.000	22.220	195.700	38.300	512.55	0.19	13.21	52.55

稀土元素相对亏损,而重稀土元素相对富集的特征,但不同测点轻稀土元素亏损与重稀土富集程度存在一些差异,其 Lu_N/Sm_N 值为7.56~230.30,有的碎屑锆石稀土元素配分模式显示重稀土元素明显上翘;148个碎屑锆石多数具有正Ce异常与负Eu异常,但不同测点存在一些差异,Ce/Ce*值为1.11~364.56, Eu/Eu*值为0.05~1.09。石英岩中12个变质重结晶型锆石的稀土元素总含量较高,为 $271.93 \times 10^{-6} \sim 740.36 \times 10^{-6}$ (图8f,表4),在球粒陨石标准化稀土元素配分图中,它们轻稀土元素亏损,而重稀土元素富集,相应的 Lu_N/Sm_N 值为42.99~92.57(表4);12个变质重结晶型锆石具有明显的正Ce异常与负Eu异常,但不同测点存在一些微小的差异,Ce/Ce*值为14.65~84.40, Eu/Eu*值为42.99~92.57。

7 锆石 Hf 同位素特征

在锆石 U-Pb 测年的基础上,选择了51个新太古代晚期岩浆型碎屑锆石进行了原位 Lu-Hf 同位素分析,其具体分析结果见表5。可以明显看出,51个测点的 $^{176}Lu/^{177}Hf$ 值为0.000384~0.001917, $^{176}Hf/^{177}Hf$ 值为0.281240~0.281441。利用每个锆石测点已获得的 $^{207}Pb/^{206}Pb$ 年龄进行计算,获得 $^{176}Hf/^{177}Hf$ 值为0.281209~0.281349, $\epsilon_{Hf}(t)$ 值为1.36~6.37,一阶段和两阶段模式年龄分别为2779~2592 Ma 和 2950~2629 Ma(图9)。

8 讨论

8.1 官都岩群沉积时代

官都岩群是赞皇杂岩中重要的变质地层单元之一,其沉积时代的准确限定对于客观恢复赞皇杂岩与华北克拉通中部造山带新太古代-古元古代构造演化历史具有重要的意义,但有关其形成时代目前还存在不同认识。早期在开展赞皇地区1:20万区域地质调查时将赞皇岩群自下而上划分为放甲铺组、北赛组、红鹤组与石家栏组(河北省地质矿产局,1989;王启超等,2008)。1:5万临城幅等区域地质调查与新编的1:50万河北省地质图认为赞皇地区存在以红鹤组二段角闪质岩层为核部的倒转向斜,并将红鹤组改名为“官都组”或“官都群”;同时指出官都岩群与新太古代变质侵入体之间为不整合接触

关系,而侵入官都岩群的黄岔岩体的锆石 U-Pb 一致线年龄为2210 Ma(王启超等,2008)。因此,结合赞皇地区太古宙地质体多数 U-Pb、Sm-Nd 年龄在2450 Ma 左右,1:5万临城幅等区域地质调查报告推测官都岩群的形成时代可能为2450~2061 Ma(王启超等,2008)。

近年来,不同学者对官都岩群与黄岔花岗岩岩体进行了 SHRIMP 或 LA-ICP-MS 锆石 U-Pb 测年。其中,Tang 等(2016)对官都岩群大理岩开展了锆石 U-Pb 测年,获得了13个锆石 U-Pb 年龄,并认为官都岩群的沉积时代为2033~1900 Ma;Li 等(2016)对官都岩群泥质片岩也开展了类似的工作,亦认为官都岩群沉积时代为古元古代。值得指出的是,Tang 等(2016)与 Li 等(2016)尽管对官都岩群开展了碎屑锆石 U-Pb 测年,但由于测点数相对较少,且对于经历了高绿片岩相-高角闪岩相变质的官都岩群而言,其获得碎屑锆石的最小一组表面年龄可能比其真实年龄偏小,提出官都岩群形成属于古元古代的认识值得商榷。

Wang 等(2015)与李伦等(2017)对侵入官都岩群的黄岔岩体开展系统的锆石 U-Pb 测年,从4个样品岩浆锆石中获得了十分一致的 U-Pb 年龄,分别为 2517 ± 20 Ma、 2513 ± 13 Ma、 2506 ± 10 Ma 与 2488 ± 6 Ma,并根据黄岔岩体局部侵入官都岩群的野外地质关系,推测官都岩群的形成时代为太古宙,而非古元古代。

本文对官都岩群中黑云变粒岩与石英岩中碎屑锆石开展了系统 U-Pb 测年,并获得了271个有效的碎屑锆石年龄,2个样品获得最年轻一组碎屑锆石中靠近谐和线附近且最大 $^{206}Pb/^{206}Pb$ 加权平均年龄分别为 2544 ± 9 Ma 与 2536 ± 4 Ma,大致限定了官都岩群的最大沉积时代。结合区域上,官都岩群被黄岔花岗岩岩体侵入的地质关系(Wang *et al.*, 2017a; 李伦等,2017),初步限定官都岩群的沉积时代为新太古代末期,但更准确的沉积时代及其与赞皇岩群的关系有待进一步研究。

8.2 官都岩群物质源区

从官都岩群碎屑锆石阴极发光图像与稀土元素配分曲线图(图4,图6)可以明显看出,绝大多数碎屑锆石发育典型的岩浆震荡环带与岩浆锆石稀土元素配分模式,指示官都岩群的物源区主要来自中酸性岩浆岩。此外,TIMA 矿物相扫描分析结果(图5,图7)表明,在官都岩群部分碎屑锆石内部含有长英

表 4 赞皇杂岩官都岩群石英锆石稀土元素分析结果
Table 4 Rare earth element compositions of zircons from quartzites of the Guandu Group in the Zanhuan Complex

样品号	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Σ REE	Eu/Eu *	Ce/Ce *	La_N/Sm_N	$w_B/10^{-6}$
碎屑锆石																			
21ZT22-1-130	0.007 0	15.060 0	0.101 0	1.590 0	3.050 0	1.018 0	16.740 0	5.650 0	73.900 0	30.470 0	159.100 0	34.310 0	326.100 0	73.100 0	740.20	0.35	45.04	144.37	
21ZT22-1-30	0.032 0	12.660 0	0.505 0	8.160 0	10.150 0	1.325 0	41.400 0	11.260 0	120.200 0	39.930 0	171.700 0	31.620 0	253.800 0	48.470 0	751.21	0.17	7.59	28.77	
21ZT22-1-61	0.021 0	12.990 0	0.078 0	1.190 0	2.970 0	0.258 0	16.120 0	5.190 0	61.000 0	22.130 0	101.700 0	20.030 0	174.400 0	34.140 0	452.22	0.09	46.67	69.24	
21ZT22-1-42	0.028 0	6.420 0	0.057 0	1.010 0	2.280 0	0.343 0	12.600 0	4.000 0	46.400 0	16.580 0	74.900 0	14.800 0	130.700 0	25.490 0	335.61	0.16	29.21	67.34	
21ZT22-1-56	0.024 0	7.320 0	0.231 0	3.920 0	7.070 0	0.750 0	34.600 0	9.570 0	106.100 0	36.030 0	155.400 0	29.060 0	238.900 0	45.900 0	674.88	0.12	9.44	39.11	
21ZT22-1-76	0.025 0	5.120 0	0.023 0	0.570 0	1.630 0	0.435 0	11.770 0	4.170 0	54.600 0	22.010 0	110.600 0	23.370 0	216.200 0	46.340 0	496.86	0.22	48.14	171.25	
21ZT22-1-41	0.026 0	15.580 0	0.164 0	2.120 0	4.300 0	0.431 0	22.470 0	6.930 0	79.600 0	28.450 0	129.400 0	24.810 0	212.700 0	40.880 0	567.86	0.11	27.73	57.27	
21ZT22-1-145	0.004 0	10.930 0	0.122 0	1.850 0	3.890 0	0.739 0	25.900 0	9.090 0	122.900 0	52.200 0	267.500 0	57.270 0	515.200 0	108.700 0	1176.30	0.17	27.45	168.32	
21ZT22-1-53	0.027 0	8.220 0	0.148 0	3.010 0	6.700 0	0.770 0	36.300 0	10.380 0	119.100 0	40.800 0	178.000 0	33.680 0	276.800 0	52.900 0	766.84	0.12	16.07	47.56	
21ZT22-1-38	0.029 0	41.110 0	0.288 0	3.000 0	4.040 0	1.700 0	16.860 0	4.930 0	58.600 0	22.070 0	111.100 0	24.300 0	237.600 0	53.800 0	579.65	0.54	32.91	80.22	
21ZT22-1-46	0.015 0	11.700 0	0.069 0	1.260 0	2.730 0	0.245 0	16.210 0	4.900 0	59.600 0	21.410 0	99.200 0	19.180 0	165.300 0	32.380 0	434.20	0.09	48.32	71.45	
21ZT22-1-43	0.114 0	34.500 0	0.705 0	7.520 0	8.870 0	3.430 0	32.700 0	8.860 0	92.400 0	31.400 0	147.200 0	30.800 0	288.000 0	60.100 0	746.60	0.54	14.27	40.81	
21ZT22-1-78	0.234 0	8.090 0	0.060 0	1.010 0	2.420 0	0.208 0	12.550 0	3.960 0	47.100 0	16.870 0	78.300 0	15.660 0	134.600 0	26.480 0	347.54	0.09	16.33	65.91	
21ZT22-1-28	0.320 0	24.000 0	0.186 0	1.930 0	3.050 0	0.560 0	17.800 0	5.570 0	69.900 0	26.130 0	132.300 0	28.610 0	267.600 0	54.100 0	632.06	0.18	23.71	106.85	
21ZT22-1-58	0.068 0	20.030 0	0.116 0	2.100 0	4.630 0	0.255 0	25.460 0	7.950 0	94.400 0	33.950 0	153.000 0	30.240 0	257.300 0	48.410 0	677.91	0.06	43.43	62.98	
21ZT22-1-51	0.099 0	13.130 0	0.101 0	1.740 0	3.920 0	0.309 0	21.640 0	6.710 0	78.200 0	27.550 0	122.400 0	23.710 0	200.400 0	38.520 0	538.43	0.08	29.00	59.19	
21ZT22-1-50	0.013 0	6.340 0	0.182 0	3.300 0	7.130 0	1.151 0	32.600 0	9.350 0	103.200 0	33.900 0	149.500 0	27.290 0	226.600 0	44.100 0	644.66	0.19	10.51	37.26	
21ZT22-1-106	0.065 0	13.530 0	0.083 0	1.800 0	3.510 0	0.395 0	21.030 0	6.690 0	78.700 0	27.340 0	121.200 0	23.370 0	207.000 0	38.040 0	542.75	0.11	38.46	65.28	
21ZT22-1-72	0.007 0	9.250 0	0.164 0	2.570 0	4.840 0	0.648 0	24.300 0	6.940 0	79.200 0	27.400 0	121.400 0	22.970 0	197.100 0	37.700 0	534.33	0.15	17.22	46.92	
21ZT22-1-71	0.027 0	32.300 0	0.104 0	1.630 0	2.780 0	0.961 0	12.630 0	3.820 0	44.800 0	17.950 0	95.300 0	21.530 0	216.500 0	50.400 0	500.73	0.42	87.33	109.21	
21ZT22-1-20	0.018 0	9.970 0	0.098 0	1.780 0	3.110 0	0.419 0	15.810 0	4.980 0	56.000 0	20.040 0	89.300 0	17.470 0	151.700 0	30.040 0	400.74	0.15	29.42	58.18	
21ZT22-1-48	0.088 0	9.260 0	0.913 0	13.120 0	17.500 0	2.420 0	73.900 0	19.040 0	197.100 0	63.600 0	264.700 0	47.200 0	389.000 0	69.200 0	1167.04	0.18	3.03	23.82	
21ZT22-1-59	0.317 0	82.200 0	1.823 0	21.920 0	24.890 0	9.670 0	81.400 0	19.210 0	178.100 0	53.160 0	221.700 0	43.030 0	370.500 0	72.250 0	1180.17	0.60	13.09	17.49	
21ZT22-1-73	0.008 0	18.490 0	0.086 0	1.540 0	3.660 0	0.199 0	20.200 0	6.590 0	79.600 0	28.190 0	131.800 0	25.100 0	216.000 0	41.480 0	572.94	0.06	64.35	68.27	
21ZT22-1-68	0.009 0	17.610 0	0.177 0	3.430 0	6.630 0	0.400 0	32.600 0	9.710 0	110.400 0	38.270 0	167.600 0	31.960 0	267.600 0	49.830 0	736.23	0.07	30.27	45.27	
21ZT22-1-32	0.012 0	8.430 0	0.227 0	3.500 0	6.870 0	0.849 0	30.600 0	9.030 0	99.300 0	33.810 0	146.600 0	28.070 0	228.600 0	43.660 0	639.56	0.15	11.29	38.28	
21ZT22-1-133	0.014 0	8.750 0	0.291 0	5.140 0	8.500 0	1.510 0	35.200 0	10.000 0	107.300 0	35.190 0	151.000 0	28.200 0	234.200 0	44.120 0	669.42	0.23	9.16	31.27	
21ZT22-1-127	0.011 0	25.140 0	0.017 0	0.600 0	1.440 0	0.520 0	7.700 0	2.507 0	28.910 0	11.410 0	58.900 0	13.300 0	133.200 0	30.260 0	313.92	0.38	364.56	126.58	
21ZT22-1-70	0.024 0	21.540 0	0.083 0	1.480 0	3.860 0	0.212 0	22.190 0	7.350 0	89.200 0	32.520 0	148.100 0	29.170 0	247.700 0	47.030 0	650.46	0.05	72.20	73.39	
21ZT22-1-60	0.036 0	11.720 0	0.235 0	4.400 0	7.410 0	0.810 0	34.300 0	9.810 0	116.800 0	38.500 0	175.000 0	33.300 0	279.000 0	51.400 0	762.72	0.13	14.59	41.78	
21ZT22-1-57	0.014 0	12.410 0	0.259 0	5.260 0	9.950 0	0.744 0	42.800 0	12.800 0	135.000 0	45.850 0	200.300 0	36.320 0	300.100 0	56.470 0	858.28	0.09	14.56	34.19	
21ZT22-1-16	1.430 0	34.980 0	0.980 0	6.700 0	5.850 0	1.710 0	24.400 0	6.940 0	78.000 0	27.880 0	132.800 0	28.420 0	256.700 0	53.600 0	660.39	0.38	6.99	55.19	
21ZT22-1-82	1.650 0	44.940 0	0.688 0	4.560 0	4.190 0	1.290 0	19.520 0	5.820 0	70.000 0	25.780 0	127.400 0	26.750 0	252.700 0	54.080 0	639.37	0.36	10.34	77.75	
21ZT22-1-54	0.088 0	7.580 0	0.215 0	5.280 0	9.400 0	1.350 0	46.200 0	13.190 0	141.800 0	47.300 0	197.200 0	36.900 0	299.500 0	58.300 0	864.30	0.16	9.41	37.36	
21ZT22-1-123	0.065 0	19.670 0	0.126 0	2.600 0	5.060 0	0.459 0	24.360 0	7.090 0	80.900 0	28.730 0	130.000 0	25.930 0	222.500 0	43.490 0	590.98	0.10	40.12	51.77	
21ZT22-1-39	0.065 0	8.430 0	0.064 0	1.390 0	2.780 0	0.361 0	15.710 0	4.730 0	56.500 0	19.980 0	90.600 0	17.820 0	152.900 0	30.450 0	401.78	0.13	29.06	65.98	
21ZT22-1-150	0.073 0	36.690 0	0.139 0	1.460 0	2.010 0	0.914 0	10.120 0	3.110 0	40.270 0	16.190 0	89.100 0	20.860 0	222.800 0	52.660 0	496.40	0.51	67.70	157.81	
21ZT22-1-93	0.046 0	4.720 0	0.049 0	0.920 0	2.280 0	0.332 0	11.690 0	3.608 0	41.230 0	14.640 0	67.700 0	13.330 0	116.500 0	23.470 0	300.52	0.16	21.73	62.01	

续表 4-1
Continued Table 4-1

样品号	La	Ce	Pr	Nd	Sm	Eu	Cd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Σ REE	Eu/Eu *	Ce/Ce *	Lu _N /Sm _N
21ZT22-1-65	0.033 0	14.570 0	0.651 0	12.200 0	18.900 0	1.770 0	77.300 0	20.710 0	224.600 0	72.100 0	301.400 0	53.800 0	427.000 0	79.300 0	1 304.33	0.12	6.81	25.27
21ZT22-1-34	0.041 0	10.960 0	0.134 0	1.500 0	3.240 0	0.287 0	16.100 0	5.210 0	58.500 0	20.730 0	93.600 0	18.670 0	160.100 0	30.230 0	419.33	0.10	22.62	56.20
21ZT22-1-33	0.013 0	11.680 0	0.029 0	0.810 0	1.740 0	0.116 0	9.970 0	3.430 0	41.900 0	16.050 0	76.000 0	15.500 0	138.100 0	27.330 0	342.67	0.07	106.24	94.61
21ZT22-1-114	0.007 0	43.000 0	0.049 0	0.920 0	2.290 0	0.852 0	12.190 0	3.630 0	45.100 0	17.700 0	95.400 0	22.350 0	232.500 0	55.110 0	531.10	0.40	257.69	144.96
21ZT22-1-95	0.020 0	11.450 0	0.069 0	0.950 0	1.930 0	0.305 0	9.360 0	3.130 0	36.500 0	13.420 0	63.400 0	13.440 0	122.700 0	24.730 0	301.4	0.18	46.16	77.18
21ZT22-1-90	0.044 0	11.900 0	0.087 0	1.750 0	3.550 0	0.358 0	19.980 0	6.160 0	70.700 0	25.160 0	114.800 0	22.160 0	192.200 0	36.730 0	505.58	0.10	35.37	62.32
21ZT22-1-86	0.054 0	9.410 0	0.122 0	1.320 0	2.550 0	0.631 0	12.580 0	4.000 0	46.780 0	16.460 0	76.400 0	15.060 0	131.200 0	25.910 0	342.48	0.28	20.34	61.20
21ZT22-1-74	0.053 0	14.530 0	0.824 0	12.000 0	18.900 0	1.690 0	74.500 0	20.240 0	215.900 0	70.200 0	292.600 0	53.000 0	429.000 0	76.900 0	1 280.34	0.12	5.34	24.51
21ZT22-1-52	0.017 0	9.480 0	0.445 0	9.100 0	15.200 0	1.430 0	67.100 0	18.460 0	190.100 0	61.600 0	260.200 0	47.000 0	381.000 0	69.400 0	1 130.53	0.12	6.51	27.50
21ZT22-1-36	0.012 0	6.690 0	0.068 0	1.320 0	2.660 0	0.288 0	14.050 0	4.370 0	51.500 0	18.570 0	85.900 0	16.700 0	146.300 0	28.730 0	377.16	0.12	28.53	65.06
21ZT22-1-29	0.003 0	9.980 0	0.042 0	0.730 0	1.900 0	0.120 0	9.960 0	3.240 0	39.800 0	15.040 0	70.800 0	14.110 0	124.600 0	24.580 0	314.11	0.07	71.72	77.93
21ZT22-1-5	0.026 0	9.100 0	0.389 0	5.550 0	10.960 0	2.400 0	67.700 0	22.560 0	282.200 0	106.400 0	503.800 0	99.700 0	859.000 0	167.800 0	2 137.59	0.21	7.07	92.22
21ZT22-1-128	0.021 0	8.220 0	0.350 0	5.590 0	8.020 0	0.829 0	34.900 0	9.750 0	107.100 0	35.460 0	153.000 0	28.270 0	237.100 0	44.480 0	673.09	0.13	7.12	33.41
21ZT22-1-89	0.258 0	29.550 0	0.169 0	2.060 0	3.120 0	1.030 0	15.800 0	4.860 0	55.900 0	21.160 0	107.500 0	23.740 0	234.700 0	51.300 0	551.15	0.37	33.68	99.04
21ZT22-1-40	1.810 0	26.000 0	0.800 0	5.200 0	5.080 0	0.306 0	26.400 0	8.130 0	94.900 0	33.360 0	148.400 0	29.150 0	240.700 0	46.110 0	666.35	0.07	5.29	54.68
21ZT22-1-25	0.018 0	10.040 0	0.401 0	7.490 0	12.700 0	1.510 0	57.500 0	15.970 0	168.700 0	56.150 0	235.500 0	43.710 0	353.900 0	66.390 0	1 029.88	0.14	7.64	31.49
21ZT22-1-96	0.005 0	8.200 0	0.095 0	1.310 0	2.880 0	0.373 0	15.830 0	4.990 0	58.800 0	20.870 0	96.100 0	18.840 0	160.700 0	31.880 0	420.80	0.13	26.24	66.68
21ZT22-1-88	0.002 0	11.170 0	0.063 0	1.090 0	2.370 0	0.203 0	13.980 0	4.420 0	54.100 0	19.610 0	91.100 0	18.110 0	153.300 0	30.360 0	399.88	0.08	54.25	77.16
21ZT22-1-8	0.018 0	13.650 0	0.143 0	2.110 0	4.580 0	0.581 0	22.390 0	6.860 0	79.500 0	26.820 0	122.800 0	23.710 0	199.900 0	38.130 0	541.19	0.14	28.21	50.15
21ZT22-1-47	0.058 0	11.510 0	0.078 0	1.240 0	2.450 0	0.195 0	13.640 0	4.440 0	53.200 0	19.420 0	89.000 0	17.630 0	152.900 0	29.510 0	395.27	0.08	35.29	72.55
21ZT22-1-35	0.032 0	13.850 0	0.432 0	6.870 0	13.360 0	1.130 0	64.600 0	17.540 0	195.300 0	64.200 0	266.800 0	49.500 0	399.700 0	72.800 0	1 166.11	0.10	9.67	32.82
21ZT22-1-160	0.039 0	7.650 0	0.122 0	1.570 0	2.770 0	0.545 0	13.670 0	4.010 0	46.190 0	16.320 0	75.100 0	14.460 0	127.400 0	25.140 0	334.99	0.22	17.26	54.67
21ZT22-1-134	0.047 0	15.600 0	0.041 0	0.700 0	1.270 0	0.543 0	6.680 0	1.966 0	21.850 0	8.230 0	41.700 0	9.270 0	93.000 0	20.800 0	221.70	0.46	81.10	98.65
21ZT22-1-44	0.067 0	15.020 0	0.112 0	1.300 0	2.130 0	0.563 0	10.970 0	3.680 0	45.100 0	16.170 0	77.200 0	15.970 0	137.700 0	27.290 0	353.27	0.29	33.58	77.18
21ZT22-1-31	0.087 0	14.940 0	0.151 0	2.540 0	4.760 0	0.531 0	22.250 0	6.650 0	76.600 0	26.590 0	120.800 0	23.690 0	203.300 0	40.840 0	543.73	0.13	24.95	51.68
21ZT22-1-24	0.092 0	9.610 0	0.292 0	3.920 0	6.110 0	0.930 0	27.000 0	7.890 0	89.200 0	30.620 0	133.700 0	25.910 0	219.200 0	43.100 0	597.57	0.19	9.07	42.49
21ZT22-1-159	0.610 0	35.600 0	0.500 0	3.940 0	4.320 0	1.370 0	17.290 0	4.880 0	56.200 0	20.890 0	106.100 0	23.250 0	229.900 0	52.050 0	556.80	0.42	14.84	72.58
21ZT22-1-144	0.269 0	9.390 0	0.330 0	3.110 0	5.560 0	0.636 0	26.000 0	7.430 0	84.300 0	30.200 0	134.800 0	25.540 0	223.400 0	43.500 0	594.47	0.13	6.66	47.13
21ZT22-1-138	0.057 0	4.630 0	0.000 0	0.049 0	0.430 0	0.144 0	1.650 0	0.490 0	6.630 0	2.880 0	16.320 0	4.490 0	47.900 0	13.630 0	99.30	0.46	63.24	190.93
21ZT22-1-129	0.088 0	14.250 0	0.374 0	7.700 0	14.690 0	1.360 0	64.800 0	17.990 0	198.100 0	64.900 0	275.700 0	49.900 0	400.700 0	74.200 0	1 184.75	0.11	10.81	30.43
21ZT22-1-121	0.057 0	12.620 0	0.124 0	2.120 0	4.530 0	0.365 0	23.420 0	7.200 0	82.200 0	28.070 0	127.100 0	24.490 0	204.200 0	39.100 0	555.60	0.09	26.72	51.99
21ZT22-1-99	118.700 0	349.000 0	50.400 0	239.000 0	58.400 0	3.600 0	102.800 0	22.230 0	215.600 0	67.700 0	281.200 0	50.240 0	401.300 0	73.300 0	2 033.47	0.14	1.11	7.56
21ZT22-1-63	0.003 0	20.830 0	0.058 0	1.460 0	3.680 0	0.239 0	21.030 0	6.730 0	81.300 0	29.520 0	138.200 0	26.880 0	228.700 0	43.510 0	602.14	0.07	109.23	71.22
21ZT22-1-27	0.007 0	10.750 0	0.170 0	3.410 0	6.370 0	0.672 0	31.900 0	9.290 0	107.100 0	36.150 0	158.300 0	29.820 0	247.400 0	47.340 0	688.68	0.12	19.31	44.77
21ZT22-1-64	0.040 0	14.680 0	0.046 0	1.040 0	2.270 0	0.211 0	12.240 0	4.080 0	48.700 0	18.190 0	87.100 0	17.970 0	160.700 0	32.130 0	399.40	0.10	73.47	85.26
21ZT22-1-49	0.060 0	9.220 0	0.119 0	2.060 0	4.310 0	0.409 0	22.600 0	6.930 0	80.800 0	28.430 0	128.400 0	24.720 0	208.600 0	40.180 0	556.84	0.10	20.01	56.16
21ZT22-1-100	0.004 0	13.530 0	0.145 0	2.520 0	5.030 0	0.745 0	26.740 0	8.340 0	94.200 0	32.810 0	147.700 0	27.950 0	235.200 0	44.760 0	639.67	0.16	28.65	53.6
21ZT22-1-97	0.002 0	19.280 0	0.107 0	2.330 0	4.840 0	0.326 0	26.540 0	8.100 0	93.700 0	33.340 0	150.100 0	28.640 0	243.200 0	46.720 0	657.23	0.07	55.52	58.15
21ZT22-1-81	0.011 0	16.770 0	0.273 0	4.880 0	8.290 0	1.730 0	33.200 0	8.600 0	86.000 0	27.100 0	111.100 0	20.090 0	164.400 0	30.060 0	512.50	0.28	18.77	21.84

续表 4-2
Continued Table 4-2

样品号	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Σ REE	Eu/Eu*	Ce/Ce*	La _N /Sm _N
21ZT22-1-17	0.008 0	9.020 0	0.080 0	1.470 0	2.950 0	0.290 0	14.770 0	4.560 0	53.600 0	18.930 0	86.200 0	16.930 0	145.600 0	28.690 0	383.20	0.11	33.66	58.58
21ZT22-1-107	0.005 0	13.620 0	0.092 0	1.580 0	3.100 0	0.246 0	15.660 0	4.940 0	58.700 0	21.220 0	97.700 0	19.280 0	165.900 0	32.330 0	434.37	0.09	44.98	62.82
21ZT22-1-13	0.004 0	10.170 0	0.026 0	0.690 0	1.410 0	0.097 0	9.390 0	2.905 0	37.760 0	13.650 0	66.000 0	13.530 0	116.900 0	23.100 0	295.63	0.06	114.38	98.68
21ZT22-1-87	0.001 0	11.030 0	0.109 0	1.750 0	4.010 0	0.388 0	20.210 0	6.200 0	73.200 0	26.070 0	118.100 0	22.620 0	194.600 0	37.270 0	515.56	0.11	31.30	55.99
21ZT22-1-85	0.004 0	7.330 0	0.071 0	1.190 0	2.810 0	0.302 0	13.870 0	4.540 0	53.300 0	19.090 0	86.100 0	16.770 0	145.300 0	28.720 0	379.40	0.12	31.34	61.57
21ZT22-1-84	0.005 0	15.720 0	0.105 0	14.800 0	19.400 0	1.890 0	81.500 0	22.500 0	236.300 0	75.500 0	318.300 0	57.400 0	455.000 0	81.800 0	1 381.13	0.12	4.80	25.40
21ZT22-1-55	0.006 0	7.970 0	0.038 0	0.790 0	1.860 0	0.155 0	10.150 0	3.280 0	38.270 0	14.160 0	66.200 0	12.960 0	115.400 0	22.510 0	293.75	0.09	61.24	72.90
21ZT22-1-4	0.008 0	10.670 0	0.060 0	1.030 0	2.320 0	0.165 0	12.580 0	3.980 0	48.000 0	17.380 0	81.400 0	16.230 0	141.600 0	27.940 0	363.36	0.07	52.41	72.54
21ZT22-1-141	0.009 0	13.810 0	0.100 0	1.840 0	4.000 0	0.359 0	21.910 0	6.720 0	78.400 0	27.830 0	126.400 0	24.050 0	204.900 0	39.380 0	549.71	0.09	41.38	59.30
21ZT22-1-126	0.023 0	13.670 0	0.474 0	9.170 0	15.600 0	1.430 0	69.300 0	19.090 0	203.500 0	65.800 0	276.200 0	50.100 0	412.000 0	73.200 0	1 209.56	0.11	8.78	28.26
21ZT22-1-83	0.073 0	44.600 0	0.098 0	1.260 0	2.830 0	0.960 0	12.650 0	3.910 0	45.100 0	16.520 0	84.400 0	17.840 0	170.800 0	36.210 0	437.25	0.41	108.80	77.07
21ZT22-1-79	0.083 0	7.260 0	0.050 0	1.260 0	2.990 0	0.317 0	14.750 0	4.490 0	51.760 0	18.490 0	83.300 0	16.350 0	141.800 0	27.750 0	370.65	0.12	27.07	55.90
21ZT22-1-75	0.011 0	5.970 0	0.104 0	1.560 0	2.760 0	0.507 0	13.740 0	4.180 0	47.100 0	16.250 0	74.700 0	14.330 0	125.500 0	25.010 0	331.72	0.21	17.10	54.58
21ZT22-1-23	0.174 0	38.400 0	0.358 0	3.800 0	5.060 0	2.180 0	23.080 0	6.550 0	69.200 0	23.720 0	109.400 0	22.520 0	205.200 0	42.440 0	552.08	0.52	27.87	50.52
21ZT22-1-111	0.009 0	13.800 0	0.093 0	1.560 0	3.580 0	0.284 0	18.960 0	5.870 0	70.600 0	25.360 0	114.200 0	22.170 0	191.800 0	37.120 0	505.41	0.08	44.35	62.46
21ZT22-1-108	0.036 0	14.890 0	0.343 0	5.170 0	10.100 0	0.890 0	47.300 0	13.370 0	149.100 0	49.800 0	214.900 0	39.100 0	322.000 0	58.300 0	925.30	0.10	12.93	34.77
21ZT22-1-139	0.008 0	11.680 0	0.263 0	5.350 0	11.150 0	1.300 0	54.700 0	15.720 0	170.700 0	57.140 0	245.000 0	44.790 0	356.600 0	66.540 0	1 040.94	0.13	13.62	35.95
21ZT22-1-22	0.012 0	7.500 0	0.059 0	1.110 0	2.590 0	0.241 0	13.430 0	4.170 0	50.100 0	18.010 0	81.900 0	16.210 0	137.800 0	27.240 0	360.37	0.10	36.49	63.35
21ZT22-1-21	0.016 0	11.890 0	0.153 0	2.820 0	5.490 0	0.550 0	30.140 0	8.940 0	103.900 0	35.910 0	158.200 0	30.080 0	252.600 0	48.600 0	689.29	0.10	23.16	53.32
21ZT22-1-124	0.086 0	15.320 0	0.086 0	1.630 0	3.630 0	0.279 0	20.450 0	6.380 0	74.900 0	27.190 0	123.800 0	23.500 0	197.900 0	38.470 0	533.62	0.08	39.48	63.84
21ZT22-1-10	0.451 0	21.640 0	0.905 0	9.970 0	11.550 0	2.030 0	53.500 0	14.990 0	171.000 0	58.500 0	260.600 0	48.500 0	396.000 0	76.700 0	1 126.34	0.21	6.19	40.00
21ZT22-1-137	0.007 0	8.190 0	0.115 0	2.520 0	5.520 0	0.646 0	30.400 0	9.110 0	105.100 0	37.000 0	164.800 0	30.840 0	258.300 0	49.570 0	702.12	0.12	21.58	54.09
21ZT22-1-110	0.004 0	20.790 0	0.099 0	2.010 0	4.580 0	0.256 0	24.600 0	8.070 0	95.800 0	34.280 0	157.100 0	30.530 0	258.800 0	48.490 0	685.41	0.06	64.16	63.77
21ZT22-1-102	0.003 0	17.810 0	0.076 0	1.400 0	3.050 0	0.185 0	17.960 0	5.770 0	69.100 0	25.600 0	117.900 0	23.220 0	197.400 0	38.430 0	517.90	0.06	71.62	75.90
21ZT22-1-19	0.001 0	8.040 0	0.073 0	1.480 0	3.100 0	0.355 0	15.650 0	4.960 0	57.780 0	20.810 0	93.800 0	18.150 0	158.900 0	30.630 0	413.73	0.13	34.01	59.52
21ZT22-1-18	0.026 0	13.660 0	0.533 0	10.820 0	17.670 0	1.590 0	73.000 0	19.980 0	211.700 0	69.100 0	292.000 0	52.200 0	419.800 0	76.000 0	1 258.08	0.12	7.80	25.91
21ZT22-1-115	0.021 0	10.010 0	0.077 0	1.220 0	2.940 0	0.229 0	15.510 0	4.800 0	57.000 0	20.460 0	93.600 0	18.580 0	159.900 0	30.970 0	415.32	0.08	36.38	63.45
21ZT22-1-77	0.024 0	5.460 0	0.034 0	0.850 0	1.690 0	0.298 0	8.750 0	2.770 0	33.140 0	12.090 0	57.600 0	11.730 0	108.200 0	22.520 0	265.16	0.19	38.86	80.27
21ZT22-1-14	0.027 0	9.680 0	0.043 0	0.790 0	1.750 0	0.108 0	10.100 0	3.320 0	40.250 0	15.070 0	70.300 0	14.300 0	125.100 0	24.310 0	315.15	0.06	55.84	83.68
21ZT22-1-94	0.164 0	14.350 0	0.980 0	14.540 0	20.600 0	3.540 0	91.200 0	24.060 0	250.600 0	82.400 0	349.000 0	62.000 0	505.800 0	97.600 0	1 516.83	0.21	4.26	28.54
21ZT22-1-91	0.240 0	7.500 0	0.055 0	1.060 0	2.240 0	0.230 0	12.410 0	3.880 0	45.930 0	16.780 0	75.600 0	15.280 0	131.100 0	25.650 0	337.96	0.11	15.40	68.98
21ZT22-1-157	0.480 0	34.200 0	0.394 0	3.190 0	4.810 0	2.200 0	17.300 0	4.880 0	53.300 0	20.300 0	103.700 0	23.350 0	240.100 0	52.000 0	560.20	0.66	18.11	65.12
21ZT22-1-104	0.017 0	9.180 0	0.214 0	3.950 0	7.710 0	0.674 0	36.600 0	11.030 0	123.100 0	42.340 0	185.500 0	34.340 0	284.100 0	54.320 0	793.08	0.10	12.91	42.44
21ZT22-1-92	0.031 0	15.050 0	0.630 0	10.800 0	17.500 0	1.509 0	76.300 0	21.350 0	227.500 0	75.000 0	316.600 0	57.060 0	454.600 0	84.200 0	1 358.11	0.11	7.27	28.98
21ZT22-1-148	0.017 0	7.820 0	0.260 0	4.490 0	8.160 0	0.925 0	37.700 0	10.530 0	113.400 0	38.100 0	162.800 0	30.500 0	251.000 0	47.600 0	713.10	0.13	9.10	35.14
21ZT22-1-146	0.630 0	14.700 0	0.500 0	3.500 0	3.360 0	0.220 0	15.990 0	5.080 0	59.200 0	21.550 0	99.900 0	19.280 0	168.300 0	33.350 0	445.56	0.08	6.06	59.79
21ZT22-1-105	0.023 0	9.520 0	0.068 0	1.190 0	2.740 0	0.263 0	15.610 0	4.930 0	58.400 0	21.000 0	96.300 0	18.560 0	161.800 0	31.350 0	421.75	0.10	38.27	68.92
21ZT22-1-136	0.003 0	11.140 0	0.088 0	1.620 0	3.320 0	0.296 0	19.580 0	6.070 0	71.200 0	24.780 0	113.200 0	22.010 0	186.400 0	35.660 0	495.37	0.09	38.77	64.70
21ZT22-1-122	0.015 0	21.490 0	0.114 0	2.120 0	4.660 0	0.295 0	25.740 0	8.280 0	96.300 0	33.940 0	157.100 0	30.040 0	257.800 0	49.110 0	686.50	0.07	55.59	63.48
21ZT22-1-117	0.065 0	8.680 0	0.177 0	3.540 0	7.500 0	0.801 0	37.500 0	10.940 0	118.800 0	40.900 0	178.400 0	33.000 0	270.800 0	51.100 0	762.20	0.12	13.26	41.04
21ZT22-1-113	0.152 0	11.300 0	1.239 0	16.310 0	21.130 0	1.980 0	81.600 0	21.460 0	219.500 0	71.300 0	292.700 0	52.410 0	420.200 0	79.300 0	1 290.58	0.13	2.70	22.61
21ZT22-1-15	0.009 0	10.660 0	0.050 0	1.120 0	2.720 0	0.247 0	14.880 0	4.770 0	57.200 0	20.310 0	94.000 0	18.280 0	154.200 0	30.470 0	408.92	0.09	61.74	67.48

续表 4-3
Continued Table 4-3

样品号	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Σ REE	Eu/Eu*	Ce/Ce*	La _N /Sm _N
21ZT22-1-26	0.001	7.570	0.065	1.310	2.540	0.290	14.250	4.240	51.560	18.470	84.300	16.400	147.000	28.770	376.77	0.12	35.93	68.23
21ZT22-1-151	0.008	11.470	0.486	8.470	14.140	1.441	63.800	17.570	189.100	62.190	263.500	47.130	382.100	71.070	1132.48	0.12	7.28	30.28
21ZT22-1-125	0.006	10.280	0.063	1.650	2.980	0.348	17.280	5.460	65.500	23.520	104.600	20.510	173.000	34.290	459.49	0.12	48.80	69.31
21ZT22-1-12	0.013	7.480	0.024	0.242	0.560	0.338	3.480	1.143	15.430	6.260	34.450	8.240	88.700	21.410	187.77	0.57	79.50	230.30
21ZT22-1-119	0.660	26.200	0.620	3.700	2.770	1.510	7.910	2.240	21.400	9.480	49.800	11.490	120.300	28.190	289.27	0.92	9.20	61.30
21ZT22-1-11	0.213	6.640	0.401	5.600	8.590	1.267	36.600	10.520	113.500	37.440	160.500	29.580	246.600	47.160	704.61	0.19	4.24	33.07
21ZT22-1-109	0.021	7.250	0.099	1.660	3.760	0.471	17.640	5.410	62.500	22.040	99.900	19.310	167.400	32.260	439.72	0.15	20.95	51.68
21ZT22-1-103	0.033	7.270	0.426	6.560	11.220	1.612	48.500	13.380	144.800	48.050	202.900	37.110	301.900	57.310	881.07	0.18	5.14	30.77
21ZT22-1-69	0.086	19.740	0.682	10.330	16.450	1.490	76.100	21.760	236.600	78.700	334.700	61.400	490.600	91.200	1439.84	0.11	8.55	33.40
21ZT22-1-135	0.023	9.880	0.087	1.830	3.180	0.393	18.230	5.690	63.900	22.780	105.100	20.380	174.900	33.910	460.28	0.12	31.88	64.23
21ZT22-1-131	0.015	10.250	0.309	6.530	12.360	1.383	56.900	16.120	171.900	57.210	241.500	44.240	357.800	66.970	1043.49	0.13	10.10	32.64
21ZT22-1-112	0.002	9.640	0.132	2.370	4.160	0.453	24.020	6.910	80.800	28.420	125.900	23.900	203.600	38.730	549.04	0.11	22.54	56.08
21ZT22-1-142	0.010	10.540	0.258	5.050	10.620	1.004	53.400	15.330	167.900	56.990	242.900	44.520	356.500	66.890	1031.91	0.11	12.49	37.94
21ZT22-1-132	0.020	10.280	0.042	0.720	1.640	0.114	9.710	3.100	39.200	15.180	70.200	14.700	127.200	24.740	316.85	0.07	63.81	90.87
21ZT22-1-6	0.004	16.790	0.075	1.710	3.720	0.272	20.510	6.490	77.100	27.590	127.700	24.800	210.200	40.540	557.50	0.08	68.05	65.64
21ZT22-1-156	0.003	16.310	0.065	1.340	2.810	0.139	16.400	5.450	64.900	23.880	112.300	22.260	191.000	36.870	493.73	0.05	76.49	79.04
21ZT22-1-149	0.008	12.050	0.274	5.200	8.240	0.854	37.700	11.160	121.600	40.970	175.400	32.810	269.200	51.080	766.55	0.12	13.50	37.34
21ZT22-1-118	0.010	3.910	0.221	3.390	6.330	1.030	29.300	7.710	85.300	28.200	121.300	22.540	188.300	37.000	534.54	0.19	5.39	35.21
21ZT22-1-45	0.035	5.050	0.080	1.390	2.530	0.486	12.760	4.000	46.470	16.100	73.600	14.440	128.900	24.810	330.65	0.21	16.67	59.07
21ZT22-1-140	0.067	7.430	0.081	1.570	3.110	0.424	17.800	5.590	63.500	22.760	103.000	19.680	169.600	32.630	447.24	0.14	21.39	63.20
21ZT22-1-98	0.064	6.800	0.097	1.720	3.380	0.646	18.400	5.460	60.600	21.170	94.700	18.240	157.100	30.750	419.13	0.20	17.21	54.80
21ZT22-1-7	0.079	7.780	0.677	9.780	13.290	1.701	56.200	15.050	159.200	51.590	217.100	39.320	317.300	60.630	949.70	0.16	3.41	27.48
21ZT22-1-2	0.139	51.170	0.769	11.320	16.840	1.580	64.600	17.050	180.700	60.830	267.100	53.280	446.200	89.600	1261.18	0.13	19.26	32.05
21ZT22-1-101	0.767	48.600	1.980	21.360	27.870	1.770	95.400	26.760	266.900	83.700	340.900	62.900	513.900	93.600	1591.91	0.39	6.60	20.23
21ZT22-1-1	0.101	19.450	0.711	10.640	15.550	1.650	63.800	18.170	194.400	62.200	258.300	48.100	384.000	69.300	1146.37	0.14	8.04	26.84
21ZT22-1-62	4.880	47.600	3.400	19.400	17.200	11.020	48.600	11.350	96.100	27.800	121.400	25.580	231.700	45.500	711.53	1.09	2.76	15.93
21ZT22-1-143	1.420	25.100	2.010	12.900	9.300	4.530	29.100	6.830	66.200	21.400	93.000	18.800	173.300	36.000	499.89	0.77	3.02	23.32
21ZT22-1-120	0.002	11.970	0.101	1.680	3.700	0.317	20.430	6.390	73.800	26.710	120.400	23.770	200.900	39.270	529.44	0.09	36.50	63.93
21ZT22-1-116	0.001	7.130	0.069	1.150	2.200	0.250	13.600	4.160	48.500	17.700	81.400	16.070	139.600	27.100	358.93	0.11	31.90	74.20
变质粘土																		
21ZT22-1-152	0.103	25.870	0.319	3.270	5.250	1.160	26.880	8.620	100.600	36.360	167.700	32.150	279.900	52.180	740.36	0.24	22.29	59.87
21ZT22-1-153	0.004	8.080	0.034	0.607	1.750	0.096	8.570	2.880	35.040	12.920	60.600	12.140	108.000	21.210	271.93	0.06	70.46	73.01
21ZT22-1-154	0.001	14.940	0.092	1.770	3.830	0.283	20.000	6.560	77.800	27.640	124.200	24.210	206.800	39.160	547.29	0.08	50.20	61.59
21ZT22-1-155	0.045	8.670	0.035	0.770	1.880	0.115	10.080	3.202	37.800	14.070	66.600	13.390	117.500	23.260	297.42	0.06	50.75	74.53
21ZT22-1-3	0.031	39.830	0.239	3.220	6.360	0.530	28.200	8.450	97.300	34.270	156.200	31.720	269.400	54.150	729.90	0.10	49.18	51.29
21ZT22-1-9	0.038	12.210	0.102	1.760	3.140	0.303	18.690	5.670	66.000	23.720	107.800	20.600	177.800	34.260	472.09	0.09	32.33	65.72
21ZT22-1-37	0.024	18.780	0.078	1.480	3.480	0.229	22.110	7.610	92.500	33.530	159.500	30.850	262.300	49.980	682.45	0.06	66.54	86.51
21ZT22-1-66	0.013	8.620	0.054	1.430	2.320	0.390	12.440	4.220	49.900	17.450	82.100	16.180	142.000	27.500	364.62	0.18	45.20	71.40
21ZT22-1-67	0.012	19.250	0.066	1.240	2.940	0.165	18.970	6.420	80.200	29.720	139.800	28.050	235.800	45.180	607.81	0.05	84.40	92.57
21ZT22-1-80	0.013	9.310	0.113	1.730	3.430	0.400	19.800	5.950	67.900	24.520	110.400	21.460	182.800	35.400	483.23	0.12	24.45	62.17
21ZT22-1-147	0.032	14.510	0.087	1.500	3.240	0.213	16.070	5.430	64.000	23.440	108.900	21.260	186.300	36.170	481.15	0.07	45.13	67.25
21ZT22-1-158	0.042	8.250	0.158	3.130	6.880	0.789	36.600	10.690	115.800	40.100	170.300	31.500	262.000	49.100	735.34	0.12	14.65	42.99

表 5 赞皇杂岩官都岩群石英岩碎屑锆石 Lu-Hf 同位素分析结果

Table 5 Lu-Hf isotopic compositions of detrital zircons from quartzites of the Guandu Group in the Zanzhuang Complex

样品分析点	年龄/Ma	$^{176}\text{Yb}/^{177}\text{Hf}$	2σ	$^{176}\text{Lu}/^{177}\text{Hf}$	2σ	$^{176}\text{Hf}/^{177}\text{Hf}$	2σ	$f_{\text{Lu/Hf}}$	$\varepsilon\text{Hf}(0)$	$\varepsilon\text{Hf}(t)$	t_{DTM2}
21ZT22-016	2 522	0.018 056	0.000 084	0.000 675	0.000 002	0.281 283	0.000 017	-0.979 663	-52.65	2.82	2 843
21ZT22-018	2 500	0.037 720	0.000 589	0.001 202	0.000 015	0.281 335	0.000 017	-0.963 783	-50.82	3.27	2 799
21ZT22-019	2 500	0.014 380	0.000 278	0.000 472	0.000 008	0.281 316	0.000 019	-0.985 781	-51.50	3.82	2 765
21ZT22-020	2 527	0.017 355	0.000 460	0.000 592	0.000 014	0.281 282	0.000 017	-0.982 167	-52.69	3.04	2 834
21ZT22-025	2 514	0.034 992	0.000 266	0.001 138	0.000 006	0.281 363	0.000 017	-0.965 737	-49.82	4.69	2 723
21ZT22-027	2 511	0.015 161	0.000 083	0.000 523	0.000 004	0.281 291	0.000 015	-0.984 254	-52.37	3.11	2 817
21ZT22-028	2 534	0.017 664	0.000 046	0.000 656	0.000 002	0.281 285	0.000 015	-0.980 253	-52.59	3.19	2 830
21ZT22-029	2 516	0.012 750	0.000 136	0.000 440	0.000 006	0.281 309	0.000 018	-0.986 762	-51.73	4.02	2 766
21ZT22-032	2 524	0.020 398	0.000 661	0.000 712	0.000 022	0.281 332	0.000 016	-0.978 542	-50.93	4.53	2 741
21ZT22-034	2 518	0.014 386	0.000 153	0.000 496	0.000 004	0.281 299	0.000 015	-0.985 065	-52.10	3.59	2 793
21ZT22-035	2 513	0.025 931	0.000 464	0.000 861	0.000 014	0.281 319	0.000 016	-0.974 075	-51.37	3.59	2 789
21ZT22-038	2 536	0.016 539	0.000 418	0.000 686	0.000 018	0.281 354	0.000 014	-0.979 342	-50.14	5.65	2 682
21ZT22-041	2 539	0.016 364	0.000 058	0.000 557	0.000 001	0.281 284	0.000 015	-0.983 230	-52.62	3.44	2 819
21ZT22-042	2 546	0.013 243	0.000 085	0.000 456	0.000 004	0.281 294	0.000 015	-0.986 268	-52.27	4.13	2 782
21ZT22-043	2 535	0.009 716	0.000 238	0.000 384	0.000 007	0.281 299	0.000 015	-0.988 435	-52.09	4.18	2 770
21ZT22-046	2 535	0.014 822	0.000 044	0.000 505	0.000 003	0.281 279	0.000 016	-0.984 802	-52.81	3.25	2 827
21ZT22-048	2 526	0.031 695	0.000 204	0.001 035	0.000 003	0.281 315	0.000 016	-0.968 830	-51.51	3.44	2 809
21ZT22-049	2 510	0.020 321	0.000 265	0.000 683	0.000 006	0.281 335	0.000 016	-0.979 440	-50.81	4.38	2 739
21ZT22-050	2 530	0.029 113	0.000 263	0.000 961	0.000 006	0.281 353	0.000 017	-0.971 059	-50.19	4.98	2 718
21ZT22-051	2 530	0.016 264	0.000 039	0.000 546	0.000 002	0.281 278	0.000 016	-0.983 548	-52.82	3.05	2 835
21ZT22-052	2 516	0.037 818	0.000 278	0.001 250	0.000 011	0.281 355	0.000 019	-0.962 359	-50.10	4.27	2 750
21ZT22-053	2 536	0.023 439	0.000 351	0.000 775	0.000 011	0.281 311	0.000 017	-0.976 668	-51.67	3.95	2 785
21ZT22-054	2 521	0.026 511	0.000 182	0.000 863	0.000 005	0.281 311	0.000 017	-0.974 005	-51.67	3.46	2 804
21ZT22-056	2 545	0.020 992	0.000 313	0.000 705	0.000 007	0.281 348	0.000 017	-0.978 772	-50.36	5.60	2 692
21ZT22-057	2 523	0.026 814	0.000 386	0.000 883	0.000 009	0.281 280	0.000 017	-0.973 401	-52.77	2.36	2 872
21ZT22-058	2 533	0.017 469	0.000 154	0.000 640	0.000 007	0.281 310	0.000 014	-0.980 719	-51.71	4.07	2 775
21ZT22-059	2 525	0.056 771	0.000 283	0.001 917	0.000 012	0.281 441	0.000 018	-0.942 266	-47.06	6.37	2 629
21ZT22-060	2 523	0.044 288	0.000 495	0.001 457	0.000 019	0.281 394	0.000 017	-0.956 114	-48.73	5.45	2 684
21ZT22-061	2 552	0.016 272	0.000 094	0.000 557	0.000 004	0.281 297	0.000 017	-0.983 219	-52.18	4.18	2 783
21ZT22-062	2 474	0.014 902	0.000 045	0.000 527	0.000 003	0.281 284	0.000 013	-0.984 133	-52.64	1.99	2 856
21ZT22-065	2 518	0.027 289	0.000 230	0.000 891	0.000 004	0.281 308	0.000 016	-0.973 163	-51.77	3.25	2 814
21ZT22-068	2 524	0.021 810	0.000 154	0.000 724	0.000 004	0.281 271	0.000 016	-0.978 180	-53.07	2.35	2 873
21ZT22-069	2 491	0.055 314	0.000 849	0.001 829	0.000 022	0.281 382	0.000 020	-0.944 901	-49.15	3.69	2 766
21ZT22-070	2 523	0.019 023	0.000 096	0.000 636	0.000 000	0.281 240	0.000 015	-0.980 832	-54.19	1.36	2 933
21ZT22-071	2 527	0.020 607	0.000 127	0.000 819	0.000 004	0.281 328	0.000 015	-0.975 329	-51.07	4.28	2 758
21ZT22-072	2 529	0.017 679	0.000 077	0.000 598	0.000 001	0.281 289	0.000 017	-0.981 988	-52.46	3.31	2 819
21ZT22-073	2 524	0.016 400	0.000 166	0.000 555	0.000 007	0.281 308	0.000 016	-0.983 293	-51.77	3.95	2 776
21ZT22-076	2 542	0.033 199	0.000 250	0.001 233	0.000 008	0.281 332	0.000 020	-0.962 863	-50.91	4.06	2 783
21ZT22-078	2 534	0.013 939	0.000 104	0.000 476	0.000 005	0.281 286	0.000 016	-0.985 670	-52.57	3.52	2 810
21ZT22-079	2 506	0.013 211	0.000 143	0.000 449	0.000 003	0.281 266	0.000 016	-0.986 479	-53.27	2.22	2 868
21ZT22-082	2 521	0.021 966	0.000 338	0.000 851	0.000 011	0.281 326	0.000 016	-0.974 376	-51.14	4.02	2 769
21ZT22-084	2 507	0.032 143	0.000 368	0.001 065	0.000 008	0.281 351	0.000 016	-0.967 924	-50.25	4.23	2 746
21ZT22-085	2 507	0.015 134	0.000 127	0.000 512	0.000 004	0.281 270	0.000 018	-0.984 585	-53.13	2.28	2 865
21ZT22-089	2 514	0.022 688	0.000 177	0.000 871	0.000 005	0.281 338	0.000 015	-0.973 754	-50.71	4.25	2 750
21ZT22-090	2 517	0.016 157	0.000 079	0.000 568	0.000 002	0.281 306	0.000 014	-0.982 897	-51.83	3.71	2 785
21ZT22-092	2 497	0.032 985	0.000 483	0.001 081	0.000 013	0.281 349	0.000 016	-0.967 433	-50.32	3.91	2 757
21ZT22-093	2 518	0.011 067	0.000 189	0.000 387	0.000 007	0.281 290	0.000 015	-0.988 338	-52.42	3.45	2 802
21ZT22-100	2 510	0.017 527	0.000 122	0.000 617	0.000 002	0.281 311	0.000 014	-0.981 429	-51.67	3.64	2 784
21ZT22-104	2 498	0.021 354	0.000 275	0.000 721	0.000 006	0.281 299	0.000 015	-0.978 297	-52.08	2.77	2 827
21ZT22-108	2 506	0.027 762	0.000 385	0.000 933	0.000 008	0.281 342	0.000 018	-0.971 894	-50.56	4.12	2 751
21ZT22-111	2 506	0.015 010	0.000 108	0.000 524	0.000 002	0.281 309	0.000 015	-0.984 230	-51.75	3.62	2 782

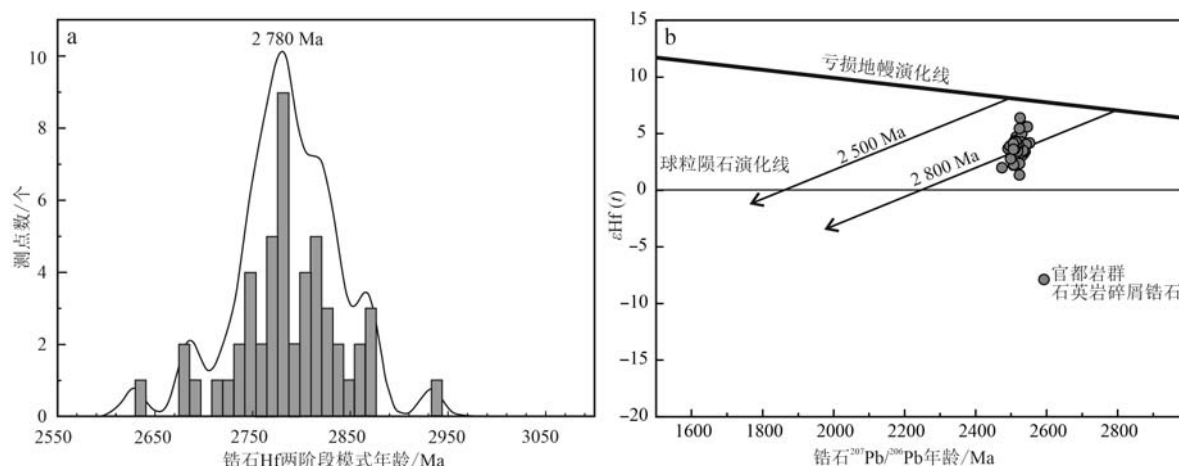


图9 赞皇杂岩官都岩群黑云变粒岩与石英岩中锆石 Hf 两阶段模式年龄直方图(a)与 $\varepsilon\text{Hf}(t) - {}^{207}\text{Pb}/{}^{206}\text{Pb}$ 年龄关系图(b)

Fig. 9 Histogram with frequency distribution diagram (a) of the zircon Hf two stage model ages and plots of zircon $\varepsilon\text{Hf}(t) - {}^{207}\text{Pb}/{}^{206}\text{Pb}$ age (b) for the biotite leptynite and quartzite from Guandu Group in the Zanzhuang Complex

质矿物包体,如钾长石+斜长石+石英+黑云母+绿泥石+磁铁矿等(图7),进一步证明赞皇地区官都岩群的物源区主要为中酸性岩浆岩。

从图10可以明显看出,赞皇地区官都岩群307颗碎屑锆石的 ${}^{207}\text{Pb}/{}^{206}\text{Pb}$ 年龄组成的年龄频率直方图显示其主峰年龄为2512 Ma,但其中也保留少量2700~2650 Ma的碎屑锆石年龄信息。赞皇地区新太古代晚期2550~2500 Ma岩浆岩分布广泛,主体为TTG片麻岩(杨崇辉等,2011b,2015; Wang *et al.*, 2017a; 李伦等,2017; 赵保强等,2019),该阶段的岩浆活动为官都岩群黑云变粒岩和石英岩的原岩提供了重要的物源。从图10还可以看出,官都岩群的碎屑锆石年龄图谱与赞皇岩群相似,以出现新太古代碎屑锆石的主峰年龄为特征,而与甘陶河群的碎屑锆石年龄图谱明显不同,后者以出现新太古代与古元古代中期碎屑锆石年龄为特征,这可能暗示官都岩群与甘陶河群是属于不同沉积时代的变质地层。

锆石 Lu-Hf 同位素体系具有与 Sm-Nd 体系相似的特性而广泛应用于岩石的物质演化研究(吴福元等,2007)。本文所研究的2550~2500 Ma碎屑锆石 $\varepsilon\text{Hf}(t)$ 值为1.36~6.37,计算结果位于2850~2700 Ma地壳演化线之间(图9)。与自然铅丢失不同,由于早期地质事件引起锆石的铅丢失会导致计算获得 $\varepsilon\text{Hf}(t)$ 值偏低。碎屑锆石两阶段 Hf 模式年龄主要为2854~2629 Ma,对应的峰值年龄为2780 Ma,与赞皇杂岩主体的新太古代 TTG 片麻岩

锆石 Hf 和全岩 Nd 同位素结果一致。上述有关官都岩群中2550~2500 Ma碎屑锆石 Hf 同位素特征表明,赞皇与华北克拉通其它地区类似(杜利林等,2020; 王建龙等,2020),2850~2700 Ma为赞皇杂岩大陆地壳生长的重要阶段。

8.3 构造意义

华北克拉通东部陆块与西部陆块内部广泛发育~2500 Ma区域变质事件,而在中部造山带内1950~1800 Ma变质作用非常强烈(Zhao *et al.*, 2012; Qian *et al.*, 2013; Tang and Santosh, 2018)。因此,长期以来中部造山带被认为是一个典型的古元古代碰撞造山带。如图1所示,近年来,在中部造山带的登峰、赞皇、左权、阜平和恒山等地区陆续发现有新太古代晚期~2500 Ma变质年龄(程裕淇等,2004; Xiao *et al.*, 2014; 杨崇辉等,2015; 肖玲玲等,2019; 王建龙等,2020)。利用 SHRIMP 锆石 U-Pb 测年技术,程裕淇等(2004)在阜平杂岩长英质麻粒岩中获得2538±14 Ma的变质年龄;类似地,王建龙等(2020)也在阜平杂岩元坊岩组浅粒岩中获得了2531±15 Ma的变质年龄。Xiao等(2014)从赞皇杂岩含榴黑云斜长片麻岩变质锆石中获得了2531±15 Ma变质年龄;肖玲玲等(2019)在左权杂岩3件角闪质片麻岩中分别获得了2500±9 Ma、2492±6 Ma与2507±15 Ma变质年龄。Huang等(2020)在登峰杂岩石榴斜长角闪岩中获得了2531±15 Ma变质年龄。Qian等(2021)在恒山杂岩 TTG 质片麻岩中获得了2501±25 Ma的变质年龄。此外,笔者在怀

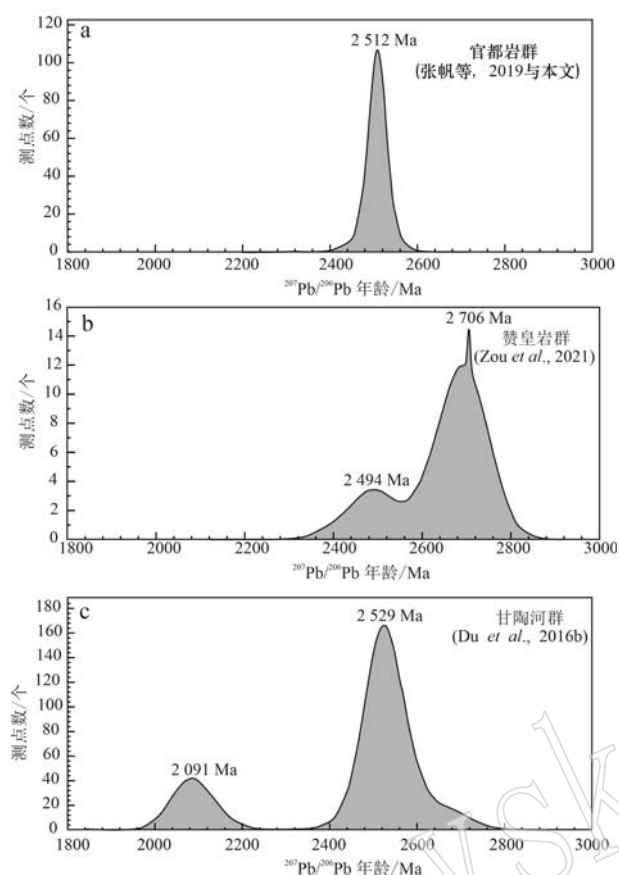


图 10 赞皇杂岩中官都岩群、赞皇岩群和甘陶河群碎屑锆石 U-Pb 年龄频率直方图

Fig. 10 U-Pb age histograms of detrital zircons from the Guandu Group, Zanzhuang Group and Gantaohu Group within the Zanzhuang Complex

安杂岩含榴紫苏斜长片麻岩中也获得了 2501 ± 25 Ma 的变质年龄(刘平等, 未发表数据)。

本文在官都岩群黑云变粒岩和石英岩变质锆石中均获得了新太古代晚期变质年龄信息, 分别为 2522 ± 34 Ma 与 2501 ± 10 Ma。本文所得变质重结晶锆石微区与核部锆石微区具有清晰的界线, 部分切割或改造了核部锆石, 均指示了变质重结晶锆石的特征(吴元保等, 2004), 说明官都岩群或其源区岩石经历了一次重要的变质事件, 这与前人在官都岩群石英岩中获得一组 2485 ± 9 Ma 的变质年龄相似(张帆等, 2019)。结合区域上在中部造山带登峰、左权、阜平、恒山和怀安地区均陆续报道了新太代晚期 ~ 2500 Ma 的变质年龄信息, 表明中部造山带经历了十分强烈的 ~ 2500 Ma 区域变质作用, 该期变质事件可能与新太古代晚期华北克拉通初步克拉通化有关, 有关其明确的构造意义还有待进一步研究。

9 结论

对官都岩群黑云变粒岩与石英岩中锆石开展了内部矿物包体、U-Pb 测年、锆石 Hf 同位素与稀土元素的综合研究与分析, 结合已发表的相关数据, 获得以下初步认识:

(1) 根据官都岩群黑云变粒岩与石英岩中碎屑锆石内部矿物包体、阴极发光图像结构与 U-Pb 年龄结果, 认为碎屑锆石中最年轻一组谐和的 $^{207}\text{Pb}/^{206}\text{Pb}$ 年龄为 2544 Ma 或 2536 Ma, 大致限定了其原岩的最大沉积时代, 结合区内官都岩群被黄岔花岗岩岩体侵入的地质关系, 说明官都岩群的沉积时代为新太古代末期, 而非古元古代。

(2) 官都岩群黑云变粒岩与石英岩碎屑锆石年龄图谱十分相似, 最主要的峰值年龄为 2512 Ma, 说明官都岩群主要物源为新太古代晚期中酸性岩浆岩; 锆石 Hf 同位素分析揭示 2850 ~ 2700 Ma 代表赞皇地区最强烈的地壳生长阶段。

(3) 与中部带其它杂岩类似, 官都岩群黑云变粒岩与石英岩中的变质锆石记录了 ~ 2500 Ma 的变质年龄, 表明华北克拉通中部造山带经历了十分强烈的 ~ 2500 Ma 区域变质作用, 该期变质事件可能与新太古代晚期华北克拉通初步克拉通化有关。

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