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# 阿尔泰递增变质带中夹层石英岩的LA-ICP-MS碎屑锆石U-Pb年龄:对沉积时限及物源的限定

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**提要**:阿尔泰造山带广泛分布各种变质沉积岩并发育典型递增变质带,变质沉积岩变质之前的沉积时代与物源特征对于限定成岩历史以及造山带演化具有重要意义。文章对采自阿勒泰组变质带中石英岩夹层样品进行了岩相学分析并采用LA-ICP-MS 方法对其碎屑锆石进行了U-Pb 年代学分析。共获得100 个谐和或近于谐和的碎屑锆石年龄,表面年龄分布范围为(443±5) Ma至(2682±19) Ma。碎屑锆石年龄主要集中在寒武纪(486~540 Ma)并具有527~535 Ma的年龄峰值,可能源于区域内同时代的岩浆活动。新元古代年龄约占1/4,少量锆石具有古中元古代甚至太古宙年龄。结合年轻碎屑锆石年龄以及直接侵入该变质带中的英云闪长岩年龄可确定石英岩原岩的沉积时限为早志留世—早泥盆世,其后发生变质作用。古老碎屑锆石在该地区缺乏对应的岩石,可能源于区内隐伏的古老基底岩石或邻区古老陆块。

**关 键 词**: 阿尔泰造山带;石英岩;碎屑锆石;LA-ICP-MS;U-Pb定年

**中图分类号**:P597 **文献标志码**:A **文章编号**:1000-3657(2016)02-0500-11

# LA-ICP-MS detrital zircon U-Pb ages of interbedded quartzite from the metamorphic belt of the Chinese Altay: Constraint on depositional time and provenance

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**Abstract**: Progressive metamorphic belts occur extensively in Chinese Altay. The depositional time and provenance of the

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metasediments in the metamorphic belts are critical for understanding the rock-forming process and the evolution of the orogen. Based on petrological analysis, the authors conducted LA-ICP-MS U-Pb analysis of detrital zircons from the quartzite narrowly interbedded in the metamorphic belt and yielded 100 concordant or nearly concordant ages with a range from (443±5) Ma to (2682±19) Ma. Most of the detrital zircons have Cambrian ages of 486~540 Ma with the peaks between 527 and 535 Ma. One fourth of the zircon grains show Neoproterozoic ages. A few detrital zircon grains formed in the Meso-Paleoproterozoic period and even in the Archean period. Combining the youngest detrital zircon age with the emplacement time of the tonalite which directly intruded in the metamorphic belt, it could be inferred that the protolith of the quartzite deposited between the Early Silurian and the Early Devonian and later experienced metamorphism. The Cambrian and even younger detrital zircons were possibly derived from the contemporaneous igneous rocks in the region. Since the lack of Precambrian rocks in the Chinese Altay, the Precambrian detrital zircons may imply a hidden ancient basement in the region or could be ascribed to a faraway source from the neighboring block.

**Key words**: Altay orogen; quartzite; detrital zircon; LA-ICP-MS; U-Pb ages

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中国阿尔泰造山带是中亚造山带的重要组成部分,一般认为由弧体系拼贴于西伯利亚板块而形成[1-4]。阿尔泰地区广泛发育花岗质侵入岩[5-10]和变质沉积岩。变质沉积岩主要包括片岩、片麻岩等岩石类型[11-13],并发育十分完善的递增变质带[14-17]。变质沉积岩中保留并记录了丰富的物质信息和演化历史[18-21],分析变质沉积岩的物质来源以及形成过程对理解地质演化具有重要意义。关于阿尔泰地区的变质沉积岩已有相关研究并取得了一些重要认识[9,19,22-23],但由于其分布广泛,成分上具有明显不同,变质沉积岩的形成时代以及物源在空间上可能存在一定差异,同时缺乏对典型递增变质带中变质沉积岩的直接研究。本文选取阿勒泰市附近阿勒泰组递增变质带中石英岩夹层样品进行LA-ICP-MS碎屑锆石U-Pb年龄分析,直接限定了递增变质带中变质沉积岩原岩的沉积时限并讨论了变质沉积岩原岩的物质来源。

## 1　区域地质

中国阿尔泰造山带是中亚造山带的一部分,呈NW向展布,向西北延至哈萨克斯坦的矿区阿尔泰和俄罗斯的山区阿尔泰,向东南连至蒙古的戈壁阿尔泰(图1-a),北邻西萨彦岭古岛弧带,南侧以额尔齐斯断裂与准噶尔地块相接[1-2,14,16,24-27]。阿尔泰造山带于晚前寒武纪处于稳定大陆边缘阶段[16,24-25,28],自寒武纪以来转变为活动陆缘环境[9,22],并长期处于俯冲环境[1-2]。根据已有的地质调查该区域一般被分成5个主要的NW-SE向延伸的构造单元[14,17,25](图1-b):(1)阿尔泰山区块体,中晚泥盆世的火山岩(安山岩和英安岩)以及晚泥盆世到早石炭世的变质沉积岩(页岩、粉砂岩、杂砂岩、砂岩、灰岩)构成了该块体的主体,多数沉积岩已经变质到绿片岩相[17]。(2)西北阿尔泰山块体,主要包括哈巴河群的浊积岩及其上覆的白哈巴群的晚奥陶世火山岩。前人认为哈巴河群形成于震旦—寒武纪[11]或南华—震旦纪[29]或新元古代(震旦纪)到中奥陶世[25];而最近的锆石年代学表明哈巴河群形成的时代下限是470 Ma,上限是384 Ma,即中奥陶世到早泥盆世,且形成于活动大陆边缘构造环境[30]。哈巴河群的岩石已经发生等倾褶皱,具有很陡的轴面,并变质到低绿片岩相。(3)中阿尔泰山块体,该块体构成了中国西北阿尔泰造山带的中心部分,主要由中奥陶世到早泥盆世的哈巴河群[30](主要是大陆碎屑组成的浊积岩)以及中—晚志留世的库鲁木提群组成。在该块体中的沉积岩已经发生了各种级别的变质,从绿片岩相到高角闪岩相,一般达到较高的变质相。该块体的北部边界为红山嘴断裂。(4)阿巴宫块体,康布铁堡组以及阿勒泰组构成了阿巴宫块体的主体,康布铁堡组主要由晚志留世到早泥盆世的弧火山岩和火山碎屑岩构成,也包括少量基性火山岩和细碧岩[2,8,25]。康布铁堡组可能形成于弧背景而非大陆裂谷背景[2,25]。阿勒泰组由中泥盆世的变质岩构成,

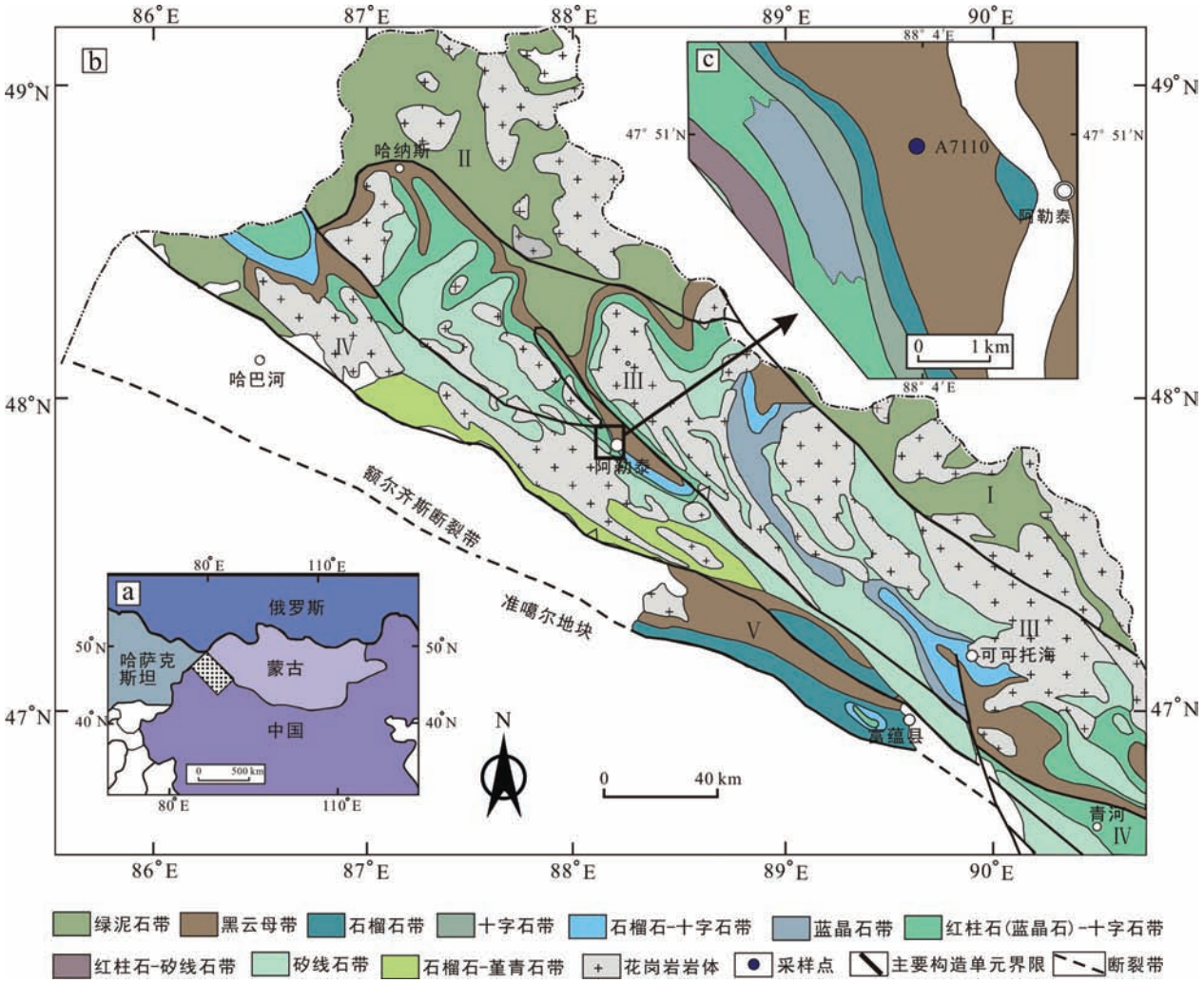


图1 阿尔泰地区地质简图(据文献[17]修改)

Ⅰ—阿尔泰山区块体; Ⅱ—西北阿尔泰山块体; Ⅲ—中阿尔泰山块体; Ⅳ—阿巴宫块体; Ⅴ—额尔齐斯块体

Fig. 1 Geological map of the Altay region (modified after reference [17])

Ⅰ−Altay Mountains ; Ⅱ−Northwest Altay; Ⅲ−Central Altai; Ⅳ−Abagong Terrane; Ⅴ−Erqis Terrane

从绿片岩相到高角闪岩相的变质带在该地块出露，局部地区达到了麻粒岩相[31]。(5)额尔齐斯块体，北部边界为科沙哈拉尔断裂，在南部，额尔齐斯断裂将额尔齐斯地块与准噶尔板块分开。该块体自西往东变窄，在其东部宽度只有 10 km 左右，其西部被第四纪沉积物覆盖，主要由早古生代到泥盆纪的沉积岩及石炭纪火山碎屑岩组成，它们已经变质到绿片岩到角闪岩相。高级片麻岩在局部地区出露，之前被认为是前寒武纪的基底[32]，而新的锆石年代学研究表明其可能形成于石炭纪[33]。阿尔泰造山带发育有蓝晶石型和红柱石型两种不同压力类型的变质带。蓝晶石型变质带从低向高出现黑云母带、石榴石带、十字石带、十字石−蓝晶石带、矽线石带；红柱石型变质带出现黑云母带、石榴石带、十字石带、十字石−红柱石带、矽线石带以及局部石榴石−堇青石带[17,31,34−35]。

## 2 样品特征

阿勒泰市西部发育有典型递增变质带，传统上归于阿勒泰组。其中变质程度较低的黑云母带中有较窄的石英岩夹层，样品A7110采自该夹层中(图1−c)。岩相学显示其主要矿物为石英(约为92%)，并含角闪石约为5%) (图2−a~c)及非常少量的黑云母(图2−d)、绿帘石和斜长石等。石英常呈变余粒

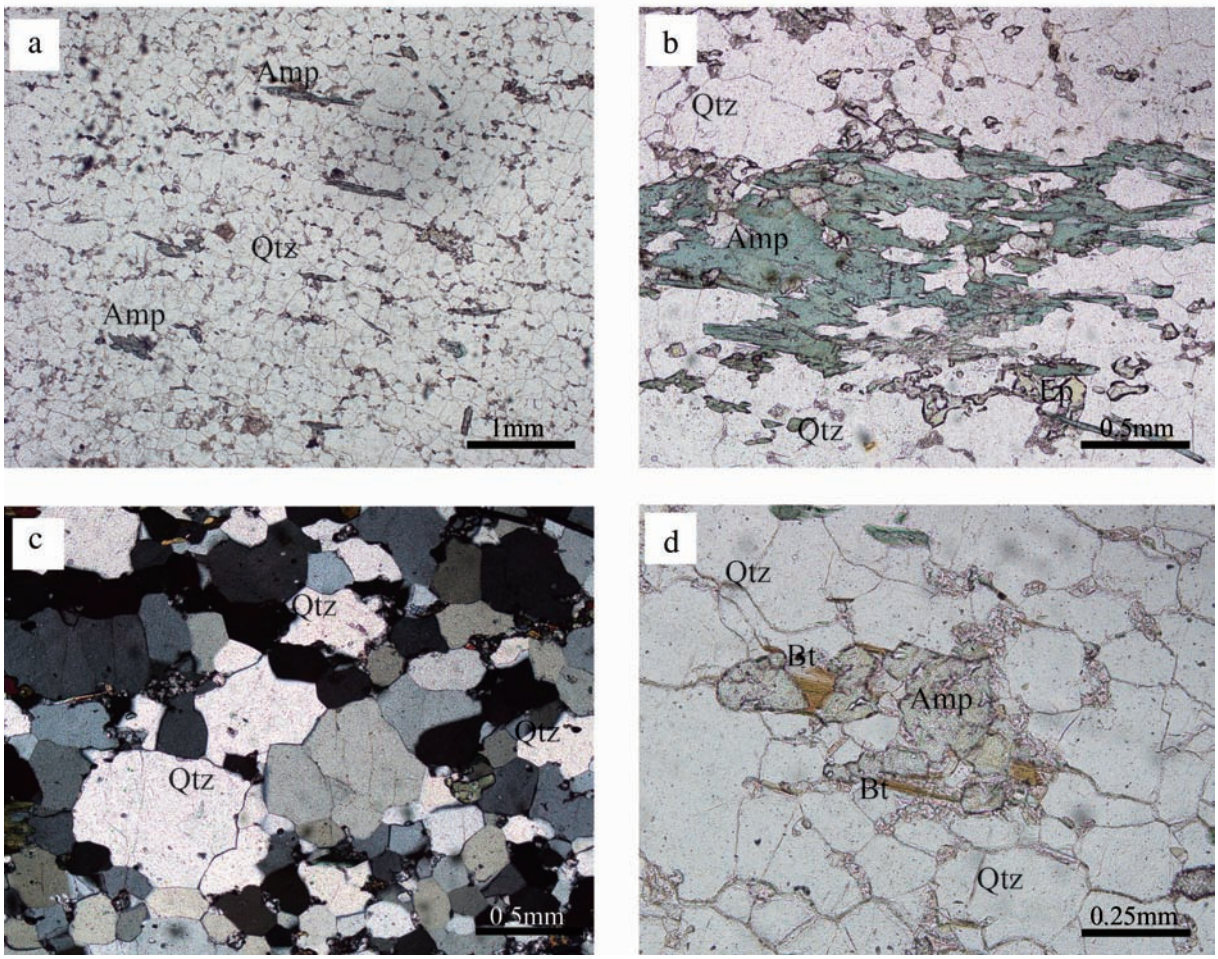


图2 石英岩岩相显微图片
Qtz—石英; Bt—黑云母; Amp—角闪石; Ep—绿帘石; a、b、d—单偏光; c—正交光
Fig. 2 Petrographic microphotos of the quartzite
Qtz-Quartz; Bt-Biotite ; Amp-Amphibole ; Ep-Epidote; a, b, d-Under plainlight; c-Under crossed nicols

状结构,大小为0.2~1 mm,可见石英颗粒间构成120°三边平衡结构(图2-c)。角闪石长径多在0.4~2 mm,单偏光下呈淡绿色,正交光下呈稻黄色及黄绿色,呈定向—半定向排列(图2-a)。斜长石已发生微弱蚀变。

## 3 分析方法

样品经磨碎淘洗和重液分选后在显微镜下完成锆石颗粒挑选。将锆石置于双面胶带上固定,注入环氧树脂制靶。在光学显微镜下拍摄反射和透射光图像,并在扫描电子显微镜上照射阴极发光(CL)图像以帮助确定合适的分析点。LA-ICP-MS锆石U-Pb定年在天津地质矿产研究所完成,激光束斑直径35 μm,用GJ-1作为外部锆石年龄标准来进行U、Pb同位素分馏校正,利用NIST610玻璃标样作为外标计算锆石样品的U、Pb、Th含量。原始数据处理方法采用中国地质大学的ICPMSDataCal程序,年龄计算及谐和图绘制使用Isoplot3.0[36]程序完成,采用$^{204}$Pb法进行普通铅校正。按照碎屑锆石的年龄范围,对于$^{206}$Pb/$^{238}$U年龄小于1200 Ma的,采用$^{206}$Pb/$^{238}$U的表面年龄,对于$^{206}$Pb/$^{238}$U年龄大于1200 Ma的,采用$^{207}$Pb/$^{206}$Pb的表面年龄[37-38]。

## 4 碎屑锆石特征与测年结果

石英岩样品碎屑锆石颗粒多呈棱柱状,阴极发光(CL)图像显示其常发育清晰的震荡环带(图3-

a~t),具有岩浆锆石形貌特征,其Th/U比值也通常大于0.1,与岩浆成因锆石特征相符;少部分锆石颗粒呈浑圆状,不发育清晰的韵律生长环带(图3-u~y),浑圆状的特征可能由长时间的搬运磨蚀造成。同时碎屑锆石边部均发育很窄的增生边,呈灰白色,可能形成于沉积成岩之后的变质过程。对锆石核部进行LA-ICP-MS碎屑锆石U-Pb年龄分析,得到100个谐和或接近谐和的数据点(表1和图4)。

样品A7110的碎屑锆石表面年龄分布范围为(443±5) Ma至(2682±19) Ma(图5),主要集中于寒武纪(486~540 Ma),多达56%,其中年龄峰值出现在527~535 Ma;该组锆石绝大多数发育清晰的震荡环带,且Th/U比值大于0.1,具有明显的岩浆成因特征,少部分锆石呈浑圆状,无清晰的震荡环带,但Th/U比值仍较高(>0.1) (表1,图3-x~y)。样品中具有新元古代年龄(542~971 Ma)的锆石较多,达28%,并在544~553 Ma和620~629 Ma年龄段上较集中。该样品最年轻碎屑锆石形成于晚奥陶世((443±5) Ma与(451±5) Ma);还有较少锆石具有中元古代年龄(1020~1094 Ma)和古元古代年龄(1731~2460 Ma)。两颗碎屑锆石显示谐和的太古宙年龄($^{206}Pb/^{207}Pb$年龄(2675±19) Ma,Th/U=0.768,Disc=-4; $^{206}Pb/^{207}Pb$年龄(2682±19) Ma,Th/U=0.651,Disc=1)。

## 5 讨 论

### 5.1 递增变质带中变质沉积岩的沉积时限

阿勒泰市西部典型递增变质带属于阿勒泰组,该组分布于哈巴河—阿勒泰—富蕴一带,其主要为

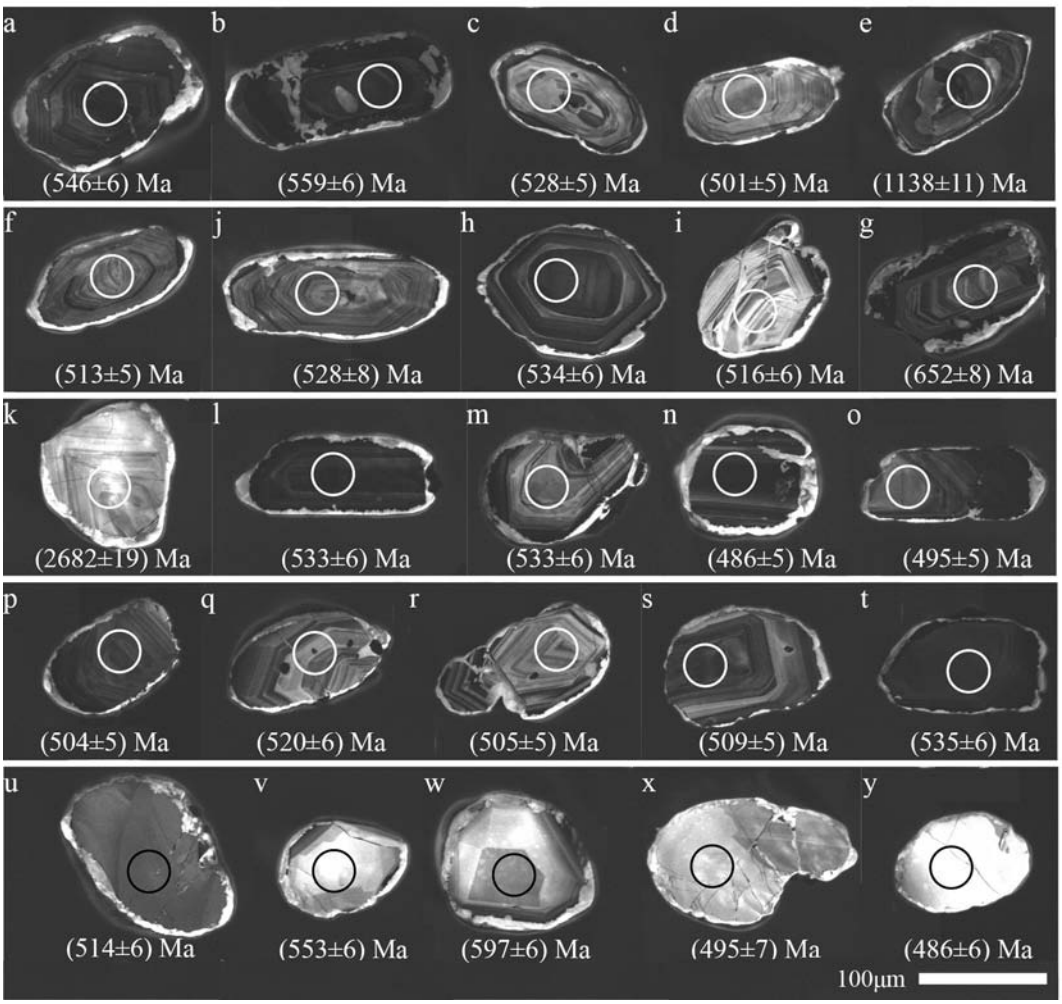


图3 石英岩碎屑锆石CL图像

Fig. 3 CL images for the detrital zircons of the quartzite

**表1　石英岩碎屑锆石U-Pb年龄测试结果**

**Table 1 U-Pb dating results for the detrital zircons of the quartzite**

| 测试点 | Th/U | 同位素比值/$10^{-6}$ | | | | | | 表面年龄/Ma | | | | | | Disc |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $^{206}Pb/^{238}U$ | 1σ | $^{207}Pb/^{235}U$ | 1σ | $^{207}Pb/^{206}Pb$ | 1σ | $^{206}Pb/^{238}U$ | 1σ | $^{207}Pb/^{235}U$ | 1σ | $^{207}Pb/^{206}Pb$ | 1σ | |
| A7110 | | | | | | | | | | | | | | |
| 01 | 0.514 | 0.0829 | 0.0009 | 0.6590 | 0.0301 | 0.0576 | 0.0027 | 514 | 6 | 514 | 24 | 516 | 103 | 0 |
| 02 | 0.586 | 0.0933 | 0.0011 | 0.7963 | 0.0593 | 0.0619 | 0.0045 | 575 | 7 | 595 | 44 | 670 | 157 | 4 |
| 03 | 0.341 | 0.0910 | 0.0010 | 0.7511 | 0.0181 | 0.0599 | 0.0014 | 561 | 6 | 569 | 14 | 599 | 49 | 2 |
| 04 | 0.104 | 0.1572 | 0.0016 | 1.5268 | 0.0204 | 0.0705 | 0.0008 | 941 | 10 | 941 | 13 | 942 | 24 | 0 |
| 05 | 0.374 | 0.0836 | 0.0009 | 0.6653 | 0.0089 | 0.0577 | 0.0007 | 518 | 5 | 518 | 7 | 519 | 25 | 0 |
| 06 | 0.756 | 0.0862 | 0.0009 | 0.7214 | 0.0096 | 0.0607 | 0.0007 | 533 | 5 | 551 | 7 | 628 | 25 | 4 |
| 07 | 0.708 | 0.1115 | 0.0012 | 0.9588 | 0.0137 | 0.0623 | 0.0008 | 682 | 7 | 683 | 10 | 686 | 27 | 0 |
| 08 | 0.446 | 0.0825 | 0.0009 | 0.6634 | 0.0259 | 0.0583 | 0.0022 | 511 | 6 | 517 | 20 | 541 | 83 | 1 |
| 09 | 1.273 | 0.0859 | 0.0009 | 0.6900 | 0.0153 | 0.0583 | 0.0012 | 531 | 5 | 533 | 12 | 540 | 47 | 1 |
| 10 | 0.675 | 0.0819 | 0.0009 | 0.6665 | 0.0161 | 0.0590 | 0.0014 | 508 | 5 | 519 | 13 | 567 | 50 | 2 |
| 11 | 0.375 | 0.0769 | 0.0008 | 0.6047 | 0.0108 | 0.0570 | 0.0009 | 478 | 5 | 480 | 9 | 491 | 36 | 1 |
| 12 | 0.161 | 0.0874 | 0.0009 | 0.7049 | 0.0093 | 0.0585 | 0.0007 | 540 | 6 | 542 | 7 | 548 | 26 | 0 |
| 13 | 0.464 | 0.0834 | 0.0009 | 0.6656 | 0.0280 | 0.0579 | 0.0024 | 516 | 6 | 518 | 22 | 526 | 89 | 1 |
| 14 | 0.228 | 0.0865 | 0.0009 | 0.6984 | 0.0093 | 0.0585 | 0.0007 | 535 | 6 | 538 | 7 | 549 | 26 | 1 |
| 15 | 0.253 | 0.0874 | 0.0009 | 0.7083 | 0.0093 | 0.0588 | 0.0007 | 540 | 6 | 544 | 7 | 559 | 25 | 1 |
| 16 | 0.861 | 0.0868 | 0.0009 | 0.6989 | 0.0093 | 0.0584 | 0.0007 | 536 | 6 | 538 | 7 | 545 | 26 | 0 |
| 17 | 0.440 | 0.0880 | 0.0009 | 0.7092 | 0.0095 | 0.0584 | 0.0007 | 544 | 6 | 544 | 7 | 547 | 26 | 0 |
| 18 | 0.488 | 0.0896 | 0.0010 | 0.7305 | 0.0264 | 0.0591 | 0.0021 | 553 | 6 | 557 | 20 | 571 | 76 | 1 |
| 19 | 0.441 | 0.0878 | 0.0009 | 0.7117 | 0.0111 | 0.0588 | 0.0008 | 542 | 6 | 546 | 9 | 560 | 31 | 1 |
| 20 | 0.359 | 0.0711 | 0.0008 | 0.5588 | 0.0365 | 0.0570 | 0.0037 | 443 | 5 | 451 | 29 | 492 | 144 | 2 |
| 21 | 0.597 | 0.0773 | 0.0008 | 0.6260 | 0.0099 | 0.0587 | 0.0009 | 480 | 5 | 494 | 8 | 557 | 32 | 3 |
| 22 | 0.705 | 0.1412 | 0.0017 | 1.3311 | 0.0803 | 0.0684 | 0.0041 | 851 | 10 | 859 | 52 | 880 | 124 | 1 |
| 23 | 0.477 | 0.0908 | 0.0009 | 0.7391 | 0.0170 | 0.0591 | 0.0013 | 560 | 6 | 562 | 13 | 569 | 48 | 0 |
| 24 | 0.768 | 0.5559 | 0.0057 | 13.9797 | 0.1818 | 0.1824 | 0.0021 | 2850 | 29 | 2748 | 36 | 2675 | 19 | -4 |
| 25 | 0.382 | 0.0883 | 0.0009 | 0.7175 | 0.0099 | 0.0589 | 0.0007 | 546 | 6 | 549 | 8 | 564 | 27 | 1 |
| 26 | 0.714 | 0.1714 | 0.0018 | 1.6669 | 0.0223 | 0.0705 | 0.0008 | 1020 | 10 | 996 | 13 | 944 | 24 | -2 |
| 27 | 0.743 | 0.4596 | 0.0048 | 10.1651 | 0.1838 | 0.1604 | 0.0028 | 2438 | 26 | 2450 | 44 | 2460 | 29 | 1 |
| 28 | 0.229 | 0.3505 | 0.0037 | 6.6135 | 0.1004 | 0.1369 | 0.0017 | 1937 | 21 | 2061 | 31 | 2188 | 22 | 6 |
| 29 | 0.580 | 0.0896 | 0.0009 | 0.7386 | 0.0103 | 0.0598 | 0.0007 | 553 | 6 | 562 | 8 | 595 | 27 | 2 |
| 30 | 0.573 | 0.0828 | 0.0009 | 0.6623 | 0.0177 | 0.0580 | 0.0015 | 513 | 5 | 516 | 14 | 531 | 56 | 1 |
| 31 | 0.539 | 0.0853 | 0.0009 | 0.6858 | 0.0117 | 0.0583 | 0.0009 | 528 | 5 | 530 | 9 | 541 | 35 | 1 |
| 32 | 0.588 | 0.0970 | 0.0010 | 0.8499 | 0.0254 | 0.0635 | 0.0019 | 597 | 6 | 625 | 19 | 726 | 62 | 5 |
| 33 | 0.101 | 0.0906 | 0.0009 | 0.7410 | 0.0100 | 0.0593 | 0.0007 | 559 | 6 | 563 | 8 | 578 | 26 | 1 |
| 34 | 0.312 | 0.1065 | 0.0013 | 0.9068 | 0.0134 | 0.0618 | 0.0008 | 652 | 8 | 655 | 10 | 666 | 27 | 0 |
| 35 | 0.493 | 0.1485 | 0.0015 | 1.4249 | 0.0208 | 0.0696 | 0.0009 | 892 | 9 | 899 | 13 | 917 | 27 | 1 |
| 36 | 0.684 | 0.1626 | 0.0017 | 1.6548 | 0.0591 | 0.0738 | 0.0026 | 971 | 10 | 991 | 35 | 1036 | 71 | 2 |
| 37 | 0.348 | 0.1747 | 0.0019 | 1.9494 | 0.0259 | 0.0809 | 0.0010 | 1038 | 11 | 1098 | 15 | 1219 | 23 | 6 |
| 38 | 0.315 | 0.1010 | 0.0011 | 0.8460 | 0.0146 | 0.0608 | 0.0010 | 620 | 7 | 622 | 11 | 630 | 34 | 1 |
| 39 | 0.618 | 0.1025 | 0.0012 | 0.8640 | 0.0199 | 0.0611 | 0.0013 | 629 | 7 | 632 | 15 | 644 | 46 | 1 |
| 40 | 0.335 | 0.0889 | 0.0009 | 0.7217 | 0.0326 | 0.0589 | 0.0026 | 549 | 6 | 552 | 25 | 563 | 95 | 0 |
| 41 | 0.308 | 0.0859 | 0.0010 | 0.7013 | 0.0140 | 0.0592 | 0.0011 | 531 | 6 | 540 | 11 | 576 | 41 | 2 |
| 42 | 0.477 | 0.0856 | 0.0011 | 0.6950 | 0.0388 | 0.0589 | 0.0032 | 530 | 7 | 536 | 30 | 562 | 119 | 1 |
| 43 | 0.376 | 0.1553 | 0.0017 | 1.5358 | 0.0384 | 0.0717 | 0.0018 | 931 | 10 | 945 | 24 | 978 | 51 | 2 |
| 44 | 0.443 | 0.0870 | 0.0010 | 0.7060 | 0.0221 | 0.0589 | 0.0018 | 538 | 6 | 542 | 17 | 562 | 67 | 1 |
| 45 | 0.500 | 0.1049 | 0.0013 | 0.8876 | 0.0328 | 0.0614 | 0.0025 | 643 | 8 | 645 | 24 | 653 | 86 | 0 |
| 46 | 0.375 | 0.3307 | 0.0034 | 4.8301 | 0.0632 | 0.1059 | 0.0012 | 1842 | 19 | 1790 | 23 | 1731 | 21 | -3 |
| 47 | 0.411 | 0.0853 | 0.0009 | 0.6928 | 0.0100 | 0.0589 | 0.0008 | 527 | 5 | 534 | 8 | 565 | 28 | 2 |
| 48 | 0.185 | 0.0817 | 0.0008 | 0.6515 | 0.0085 | 0.0578 | 0.0007 | 506 | 5 | 509 | 7 | 523 | 25 | 1 |
| 49 | 0.554 | 0.0770 | 0.0008 | 0.6061 | 0.0094 | 0.0571 | 0.0008 | 478 | 5 | 481 | 7 | 496 | 31 | 1 |
| 50 | 0.757 | 0.0851 | 0.0009 | 0.6834 | 0.0107 | 0.0582 | 0.0008 | 527 | 5 | 529 | 8 | 538 | 32 | 0 |
| 51 | 0.651 | 0.5013 | 0.0052 | 12.6665 | 0.1629 | 0.1832 | 0.0021 | 2620 | 27 | 2655 | 34 | 2682 | 19 | 1 |
| 52 | 1.064 | 0.0798 | 0.0012 | 0.6505 | 0.1036 | 0.0592 | 0.0097 | 495 | 7 | 509 | 81 | 573 | 356 | 3 |
| 53 | 0.417 | 0.0845 | 0.0009 | 0.6756 | 0.0089 | 0.0580 | 0.0007 | 523 | 5 | 524 | 7 | 530 | 26 | 0 |
| 54 | 0.750 | 0.0854 | 0.0009 | 0.6920 | 0.0151 | 0.0588 | 0.0012 | 528 | 5 | 534 | 12 | 560 | 45 | 1 |

续表1

| 测试点 | Th/U | 同位素比值/$10^{-6}$ | | | | | | 表面年龄/Ma | | | | | | Disc |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $^{206}Pb/^{238}U$ | 1σ | $^{207}Pb/^{235}U$ | 1σ | $^{207}Pb/^{206}Pb$ | 1σ | $^{206}Pb/^{238}U$ | 1σ | $^{207}Pb/^{235}U$ | 1σ | $^{207}Pb/^{206}Pb$ | 1σ | |
| A7110 | | | | | | | | | | | | | | |
| 55 | 1.643 | 0.1292 | 0.0014 | 1.2479 | 0.0370 | 0.0701 | 0.0019 | 783 | 8 | 822 | 24 | 930 | 55 | 5 |
| 56 | 0.779 | 0.0845 | 0.0009 | 0.6790 | 0.0142 | 0.0583 | 0.0011 | 523 | 5 | 526 | 11 | 541 | 43 | 1 |
| 57 | 0.508 | 0.0831 | 0.0009 | 0.6764 | 0.0100 | 0.0590 | 0.0008 | 515 | 5 | 525 | 8 | 568 | 29 | 2 |
| 58 | 0.613 | 0.0758 | 0.0008 | 0.6298 | 0.0099 | 0.0602 | 0.0009 | 471 | 5 | 496 | 8 | 612 | 31 | 5 |
| 59 | 0.828 | 0.0844 | 0.0009 | 0.6831 | 0.0090 | 0.0587 | 0.0007 | 523 | 5 | 529 | 7 | 555 | 26 | 1 |
| 60 | 0.576 | 0.0725 | 0.0007 | 0.5723 | 0.0083 | 0.0573 | 0.0008 | 451 | 5 | 460 | 7 | 502 | 29 | 2 |
| 61 | 1.111 | 0.0816 | 0.0008 | 0.6477 | 0.0085 | 0.0576 | 0.0007 | 506 | 5 | 507 | 7 | 513 | 26 | 0 |
| 62 | 0.651 | 0.0813 | 0.0008 | 0.6477 | 0.0087 | 0.0578 | 0.0007 | 504 | 5 | 507 | 7 | 522 | 26 | 1 |
| 63 | 0.961 | 0.0808 | 0.0009 | 0.6639 | 0.0209 | 0.0596 | 0.0018 | 501 | 5 | 517 | 16 | 590 | 67 | 3 |
| 64 | 0.298 | 0.1244 | 0.0013 | 1.1479 | 0.0154 | 0.0669 | 0.0008 | 756 | 8 | 776 | 10 | 835 | 24 | 3 |
| 65 | 0.250 | 0.1746 | 0.0019 | 1.8628 | 0.0254 | 0.0774 | 0.0009 | 1037 | 11 | 1068 | 15 | 1131 | 23 | 3 |
| 66 | 0.163 | 0.1023 | 0.0012 | 0.9416 | 0.0162 | 0.0668 | 0.0008 | 628 | 8 | 674 | 12 | 830 | 26 | 7 |
| 67 | 0.654 | 0.0858 | 0.0009 | 0.7100 | 0.0146 | 0.0600 | 0.0012 | 531 | 5 | 545 | 11 | 603 | 42 | 3 |
| 68 | 0.957 | 0.1233 | 0.0013 | 1.0984 | 0.0143 | 0.0646 | 0.0007 | 749 | 8 | 753 | 10 | 762 | 24 | 1 |
| 69 | 0.748 | 0.0857 | 0.0009 | 0.6970 | 0.0102 | 0.0590 | 0.0008 | 530 | 5 | 537 | 8 | 566 | 29 | 1 |
| 70 | 0.475 | 0.3450 | 0.0036 | 5.8665 | 0.0766 | 0.1233 | 0.0014 | 1910 | 20 | 1956 | 26 | 2005 | 20 | 2 |
| 71 | 0.348 | 0.0798 | 0.0008 | 0.6282 | 0.0084 | 0.0571 | 0.0007 | 495 | 5 | 495 | 7 | 497 | 26 | 0 |
| 72 | 0.595 | 0.0794 | 0.0008 | 0.6270 | 0.0084 | 0.0573 | 0.0007 | 493 | 5 | 494 | 7 | 502 | 26 | 1 |
| 73 | 0.393 | 0.0863 | 0.0009 | 0.6934 | 0.0092 | 0.0583 | 0.0007 | 533 | 6 | 535 | 7 | 541 | 26 | 0 |
| 74 | 0.439 | 0.0852 | 0.0009 | 0.6850 | 0.0094 | 0.0583 | 0.0007 | 527 | 5 | 530 | 7 | 542 | 27 | 1 |
| 75 | 0.782 | 0.0823 | 0.0009 | 0.6852 | 0.0126 | 0.0604 | 0.0010 | 510 | 5 | 530 | 10 | 618 | 37 | 4 |
| 76 | 0.465 | 0.0784 | 0.0008 | 0.6198 | 0.0082 | 0.0574 | 0.0007 | 486 | 5 | 490 | 6 | 506 | 25 | 1 |
| 77 | 0.317 | 0.0834 | 0.0009 | 0.7119 | 0.0157 | 0.0619 | 0.0013 | 517 | 5 | 546 | 12 | 670 | 45 | 6 |
| 78 | 0.711 | 0.0862 | 0.0009 | 0.6925 | 0.0108 | 0.0583 | 0.0008 | 533 | 6 | 534 | 8 | 541 | 31 | 0 |
| 79 | 1.013 | 0.1358 | 0.0014 | 1.2556 | 0.0256 | 0.0671 | 0.0013 | 821 | 9 | 826 | 17 | 840 | 40 | 1 |
| 80 | 0.063 | 0.0799 | 0.0008 | 0.6548 | 0.0101 | 0.0595 | 0.0008 | 495 | 5 | 511 | 8 | 584 | 30 | 3 |
| 81 | 0.521 | 0.0828 | 0.0009 | 0.6595 | 0.0188 | 0.0578 | 0.0016 | 513 | 5 | 514 | 15 | 521 | 61 | 0 |
| 82 | 0.413 | 0.0849 | 0.0009 | 0.7083 | 0.0092 | 0.0605 | 0.0007 | 525 | 6 | 544 | 7 | 622 | 25 | 4 |
| 83 | 0.487 | 0.0813 | 0.0008 | 0.6515 | 0.0093 | 0.0581 | 0.0007 | 504 | 5 | 509 | 7 | 534 | 28 | 1 |
| 84 | 0.278 | 0.0784 | 0.0009 | 0.6257 | 0.0407 | 0.0579 | 0.0037 | 486 | 6 | 493 | 32 | 526 | 141 | 2 |
| 85 | 0.758 | 0.0839 | 0.0009 | 0.6899 | 0.0220 | 0.0596 | 0.0018 | 520 | 6 | 533 | 17 | 590 | 67 | 3 |
| 86 | 0.420 | 0.0787 | 0.0008 | 0.6190 | 0.0081 | 0.0570 | 0.0007 | 488 | 5 | 489 | 6 | 493 | 25 | 0 |
| 87 | 0.994 | 0.0816 | 0.0008 | 0.6513 | 0.0103 | 0.0579 | 0.0008 | 505 | 5 | 509 | 8 | 526 | 32 | 1 |
| 88 | 0.687 | 0.1195 | 0.0013 | 1.1408 | 0.0217 | 0.0692 | 0.0012 | 728 | 8 | 773 | 15 | 906 | 36 | 6 |
| 89 | 0.826 | 0.0863 | 0.0009 | 0.6957 | 0.0093 | 0.0585 | 0.0007 | 534 | 5 | 536 | 7 | 547 | 26 | 1 |
| 90 | 0.331 | 0.0847 | 0.0009 | 0.6771 | 0.0090 | 0.0580 | 0.0007 | 524 | 5 | 525 | 7 | 530 | 26 | 0 |
| 91 | 0.495 | 0.0863 | 0.0009 | 0.7008 | 0.0099 | 0.0589 | 0.0007 | 534 | 6 | 539 | 8 | 562 | 27 | 1 |
| 92 | 0.282 | 0.0864 | 0.0009 | 0.6966 | 0.0091 | 0.0585 | 0.0007 | 534 | 6 | 537 | 7 | 549 | 25 | 1 |
| 93 | 0.521 | 0.0865 | 0.0009 | 0.6965 | 0.0095 | 0.0584 | 0.0007 | 535 | 6 | 537 | 7 | 546 | 26 | 0 |
| 94 | 0.404 | 0.0821 | 0.0008 | 0.6576 | 0.0098 | 0.0581 | 0.0008 | 509 | 5 | 513 | 8 | 534 | 30 | 1 |
| 95 | 0.434 | 0.0866 | 0.0009 | 0.7012 | 0.0102 | 0.0588 | 0.0008 | 535 | 6 | 540 | 8 | 558 | 29 | 1 |
| 96 | 0.391 | 0.0862 | 0.0009 | 0.6938 | 0.0094 | 0.0584 | 0.0007 | 533 | 5 | 535 | 7 | 544 | 26 | 0 |
| 97 | 0.647 | 0.0864 | 0.0009 | 0.6957 | 0.0102 | 0.0584 | 0.0008 | 534 | 6 | 536 | 8 | 545 | 29 | 0 |
| 98 | 0.715 | 0.0868 | 0.0009 | 0.7007 | 0.0104 | 0.0586 | 0.0008 | 537 | 6 | 539 | 8 | 551 | 30 | 1 |
| 99 | 1.205 | 0.1424 | 0.0015 | 1.3459 | 0.0339 | 0.0686 | 0.0017 | 858 | 9 | 866 | 22 | 886 | 50 | 1 |
| 100 | 0.255 | 0.1850 | 0.0022 | 2.1272 | 0.0331 | 0.0834 | 0.0010 | 1094 | 13 | 1158 | 18 | 1279 | 24 | 6 |

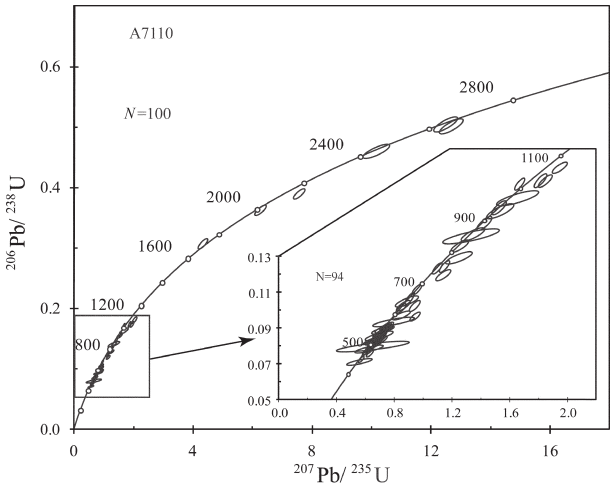


图4 石英岩碎屑锆石U-Pb年龄谐和图
Fig. 4 U-Pb concordia diagrams for detrital zircon of the quartzite

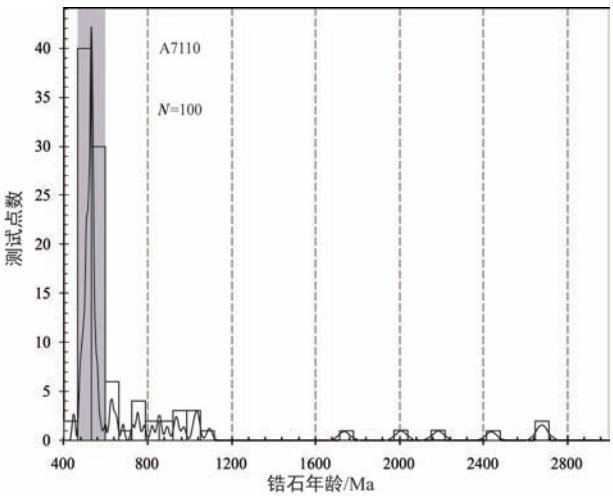


图5 石英岩碎屑锆石U-Pb年龄分布直方图
Fig. 5 U-Pb distribution histogram for detrital zircon of the quartzite

一套浅变质海相碎屑岩,同时还常发育有中—高级变质岩系[11,16]。根据其中发现的珊瑚、腕足类等化石组合,其时代被认定为中泥盆世[11,25],而对于其中中—高级变质岩系的时代归属则存在争议[12,16,39-40]。龙晓平根据阿勒泰市东南约40 km处采集的石榴矽线片麻岩碎屑锆石年轻年龄[27](约为465 Ma)以及阿勒泰市西北侵入阿勒泰组的塔尔浪花岗质侵入体年龄[10](约为412 Ma)认为塔尔浪及哈拉苏南的阿勒泰组形成时代介于中奥陶世和早泥盆世之间。阿勒泰市西部典型递增变质带中石英岩样品的碎屑锆石U-Pb年龄结果显示最年轻的碎屑锆石形成于早志留世(443 Ma),该变质沉积岩原岩应在早志留世或之后沉积形成,而直接侵入该变质带中的英云闪长岩的侵位年龄为409 Ma[41],限定了沉积时代的下限。因此,该石英岩及同层位的变质沉积岩原岩的沉积时代应在早志留世至早泥盆世之间,其后发生变质作用,形成递增变质带。该结果直接限定了阿勒泰市西部递增变质带变质沉积原岩的沉积时限。

### 5.2 递增变质带中变质沉积岩的物源分析

阿尔泰地区自寒武纪以来已处于活动陆缘阶段,广泛发育岩浆活动,形成大量侵入岩,并具有不同的峰期:500 Ma,470~460 Ma,410~380 Ma,360 Ma[8-9,42-46]。石英岩样品中多数碎屑锆石具有岩浆成因并具有寒武纪以及更年轻的年龄,主要集中于寒武纪及早奥陶世(471~540 Ma)(图5),可能主要来源于本区内的同时期侵入岩,是该时期岩浆强烈活动的反映。前寒武纪锆石主要集中于新元古代(542~971 Ma),类似的古老前寒武纪锆石同样出现于阿尔泰地区其他变质沉积岩中[22-23,47-48]。样品中还出现少量 古元古代和太古宙的碎屑锆石,这些碎屑锆石常具有较好的磨圆,推测经历了长时间的搬运与磨蚀。阿尔泰地区的哈巴河群、可可托海地区的康布铁堡组中的变质沉积岩以及阿舍勒盆地泥盆纪火山岩中[9,48-49],同样存在古元古代和太古宙的碎屑锆石。在阿尔泰地区并未发现与这些前寒武纪碎屑锆石对应的古老陆块,这些前寒武纪碎屑锆石被认为来自隐伏的古老基底岩石[12,47,50]或区外古老陆块[23]。

## 6 结　论

(1)递增变质带夹层石英岩中碎屑锆石的最小年龄为(443±5) Ma,反映了该石英岩原岩的最大沉积时限,结合直接侵入其中的英云闪长岩年龄,推测石英岩原岩的沉积时限可能为早志留世—早泥盆世之间,应代表了阿勒泰市西部典型递增变质带变质沉积原岩的沉积时限。

(2)石英岩样品中多数碎屑锆石具有寒武纪以及更年轻的年龄,应与区域内同时期的岩浆活动有关;而古老的前寒武纪碎屑锆石可能来源于隐伏的

古老基底岩石或区外古老陆块。

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